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System Innovation in the Automotive Industry: Achieving Sustainability through Micro-factory Retailing



Andrew Williams



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The Centre started work in October 2001 under the leadership of Professor Ken Peattie of the Business School, Professor Terry Marsden of the Department of City and Regional Planning and Professor Bob Lee of the Law School. The funding of the Centre covers an initial five-year period, but this should just mark the beginning of BRASS' contribution to creating more sustainable and responsible businesses locally, nationally and globally.

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Abstract

In its current form, the global automotive industry is associated with low profitability and a range of negative environmental impacts. Attempts to address these issues have largely focused on technological innovation at the level of products or processes. This paper argues that, in order to affect long lasting change towards sustainability, change processes must be undertaken at the functional and systemic level.

It is suggested that the concept of product-service systems (PSS) represents a valuable opportunity to introduce the types of function and system innovation required. The PSS concept is predicated on new forms of product ownership, stewardship, design and producer-consumer interaction. It is closely aligned with the theoretical idea of ‘closed-loop’ manufacturing and consumption systems and advocates radical changes in the behaviour of a range of stakeholders to affect sustainability improvements.

The challenge now is to investigate ways in which the PSS concept might be introduced at the empirical level. The paper suggests that the adoption of Micro-Factory Retailing (MFR) ideas offers a means of introducing such a system level change in the automotive industry. MFR is based on novel approaches to vehicle design that facilitate the economic viability of small-scale localised manufacturing sites. It is argued that such an approach to vehicle production, coupled with the proximity of MFR sites to consumers allows the adoption of a full scale PSS at local levels. Furthermore, via aspects such as the unification of the commerce and

manufacturing function, and a reduced reliance on existing infrastructures, the MFR approach may also offer distinct advantages compared with prevailing visions of PSS.

The paper concludes by discussing some areas for future research, including the importance of developing methods to evaluate the full sustainability implications of the adoption of such systems in comparison with the prevailing paradigm. There is also a brief discussion of the means by which such systems could be introduced at the empirical level via approaches such as Strategic Niche Management.

Introduction

Recent years have led to a growing awareness of the economic and environmental problems associated with the automotive industry. In the economic sense, a variety of factors including, market fragmentation and stagnation, the capital intensity of production technology and low profitability have called into question the long-term viability of a business paradigm based on mass-production and high-volume sales (Wells & Nieuwenhuis, 2001; Nieuwenhuis & Wells, 1997). There are also a wide range of environmental problems associated with the sector, including those associated with high levels of resource usage in vehicle production and waste materials when cars reach the end of their useful life. Cars collectively represent the largest single source of global air pollution, accounting for approximately 30% of industrialised country emissions and 17% of the emissions of CO² (Carley & Spapens, 1998). Efforts to address these problems have been many and wide ranging. For instance, in an attempt to overcome economic difficulties, the industry has undergone continued periods of consolidation characterised by high levels of merger and acquisition activity. These efforts to 'rationalise' production activities have been undertaken in part to maximise available economies of scale.

In terms of addressing the environmental problems associated with the production, use and end-of-life management of vehicles, a number of innovative initiatives have been undertaken throughout the automotive industry, often in response to regulatory pressures. For example, legislation enacted in by the California Air Resources Board (CARB) to promote the use of Zero Emission Vehicles (ZEV's) has lead to innovation in the design and development of, amongst other things, electric vehicles (EV's) and fuel cell technologies. In Europe too, legislation such as that related to Corporate Average Fuel Economy (CAFE) set targets for the

fuel efficiency of vehicles and led to innovation in areas such as the weight reduction and improved fuel economy of vehicles.

However, in terms of the provision of a long-term *sustainable* solution to the types of problems faced by industry, many of the strategies adopted by companies have been criticised as inadequate. It has been suggested that these strategies achieve only incremental changes in the economic or environmental performance of the industry, without fundamentally challenging the shortcomings of the prevailing paradigm. The fact remains that, even given constant restructuring and consolidation, the automotive sector remains, at least in comparison with many other sectors, relatively unprofitable (Wells & Nieuwenhuis, 2001).

In the environmental field also, it has been suggested that although the efficiency gains realised as a result of cleaner technology has reduced emissions, these have been more than offset by increased consumption and more intensive use patterns. It is precisely this type of ‘rebound effect’ that has lead many observers to suggest that for industry in general to move towards long-term sustainability, change must be facilitated beyond the level of product or process innovation and instead be realised at the system level (Brezet, 1997, Goedkoop et al, 1999, p14). Many of the initiatives that are currently, or have recently been undertaken by actors within the automotive industry have tended to stress the role of technology alone, rather than addressing the larger challenges of behavioural or system-level changes (SustainAbility/UNEP, 2001).

In terms of exploring means by which these types of system-level strategies for transforming the automotive industry to more sustainable trajectories can be achieved, the concept of product-service systems (PSS) offers an interesting perspective. This approach suggests that

the focus of economic activity should be shifted away from the manufacture and sale of products, and towards the provision of a whole range of products and services aimed at delivering a specific function. In such a way it is suggested that companies can realise profitable new business opportunities whilst simultaneously improving their environmental performance.

At the empirical level, there have been several examples of the application of PSS concepts within the automotive industry. Car-sharing and vehicle leasing schemes have introduced elements of such systems in a variety of contexts, and have enjoyed some success. However, at present, evidence of initiatives that might be said to constitute a 'complete' PSS is limited. The concept of Micro Factory Retailing (MFR) offers an opportunity to establish a radical version of such a PSS in the automotive industry. MFR is based on novel approaches to vehicle design that facilitate the economic viability of small-scale localised manufacturing sites. These sites provide a means of facilitating many of the components of PSS, such as upgrading, repair and end-of-life management. In addition, the logic of localisation facilitates a greater degree of interaction between producer and consumer, and allows many of the possible shortcomings of PSS to be overcome.

The rest of the paper is structured as follows. The section below outlines some of the prevailing sustainability problems associated with the automotive industry in more detail and describes some of the responses to these issues that have been or are currently being carried out by a variety of different stakeholders. The third section evaluates these stakeholder responses in terms of their adequacy in properly addressing sustainability concerns within the industry. In doing so, business strategies and initiatives are discussed in the context of broader theories of system innovation. It is argued that current strategies are unlikely to be

able to affect the sorts of radical change that might facilitate long-term sustainability in the industry. The next section introduces the concept of product service systems as an example of how system level change might be facilitated in the automotive industry. A further section suggests that Micro Factory Retailing represents a possible model for the introduction of the PSS concept at a practical level within the automotive industry. Factors that might influence this possibility are outlined along with some of the potential advantages of doing so. The final section outlines future work that is needed to test the viability of this approach, both in terms of its contribution towards meeting sustainability objectives and the means by which it could be practically achieved.

Sustainability and the automotive industry

Economic Sustainability

The global production system for automotive manufacture has been characterised by a high degree of consolidation amongst the major manufacturers. One of the principle driving forces behind this ongoing merger and acquisition activity is the pursuit of improved economies of scale. In the search for increased profit margins, companies have adopted a strategy of mass-production, high volume output and sales to global markets. To a large extent, the underlying reason for the adoption of these strategies is the pre-eminence of the all-steel monocoque body. Some of the production technologies associated with this type of vehicle design is highly capital intensive and means that firms are forced to sell vast quantities of individual models in order to recoup the initial investments made. This high 'break-even' point acts a barrier to the entry into the market place of new competitors and encourages the establishment of ever larger, global operations (Nieuwenhuis & Wells, 1997). Such a situation means that it is often less costly for a car company to oversupply and stockpile newly produced cars than to cut back on manufacturing capacity.

In terms of economic sustainability, the current paradigm offers limited prospects in terms of improved profit margins. In an effort to maximise the sale of vehicles made with the same production technologies many companies have adopted platform sharing strategies. Here, several vehicles are based on the same platform, but have a variety of different body shapes and are sold as different models, sometimes even as different brands. VAG has been particularly successful at this approach, using the same platform in vehicles across its VW, Audi, Skoda and Seat brands. Others have offered customers financial and other incentives in an effort to create increased demand. It is not uncommon for dealerships to provide zero percent finance packages, cash back or a years free insurance on new cars.

Although providing a partial solution to the economic pressures faced by the industry, strategies such as these do little to alleviate the underlying problems associated with the high investment, mass production and global marketing paradigm.

Environmental Sustainability

There are five principle life cycle environmental impacts associated with the manufacture and disposal of vehicles (DTI, 2000). Firstly, automobile production processes are associated with high levels of sometimes non-renewable resource use; secondly, there are impacts associated with the use of water and energy in manufacturing and the emissions caused as a result of power generation; thirdly, some elements of vehicle manufacture, particularly during painting and metal finishing, result in the emission of pollutants to air, water and land; fourthly, the extensive geographical scale of the industry means that it must be supported via global logistics and distribution systems, adding to transport mileages and exhaust emissions; and finally, at the end of their life, automobiles also represent a vast waste stream. For

example, in the European Community alone, end-of-life vehicles account for between approximately eight and nine million tonnes of waste each year (OJEC, 2000).

In addition to the array of impacts associated with production and disposal, a number of environmental consequences occur during the use phase. For example, the internal combustion engine, present in the vast majority of vehicles, emits several pollutants. Exhaust fumes from cars represent by far the biggest source of air pollution in half the world's cities (Motavilli & Spencer-Cooke, 2000). In addition, it has been suggested that the CO² content in these emissions is a major contributor to processes of climate change (SustainAbility/UNEP, 2001).

As a result of a combination of mostly legislative, but also consumer, investor, NGO and other pressures, the major global automotive manufacturers have responded to the variety environmental problems associated with the automobile in a number of ways. In terms of reducing the environmental impact associated with production, the industry has focused on sourcing renewable and recycled materials as well as implementing clean technology and environmental management systems at individual manufacturing sites and throughout supply chains. Companies have also endeavoured to reduce material inputs, change manufacturing processes to reuse by-products and, wherever possible, use alternative, less toxic materials (SMMT, 2001).

At the end of life phase, manufacturer strategies to address environmental impacts have again been largely driven by legislation. In the EU, the ELV Directive (OJEC, 2000) has sought to improve the environmental performance of all actors involved in the ELV processing chain and motivate producers to implement design changes to facilitate the easier recovery of

materials from waste vehicles. Many companies have already established programmes to improve the recyclability of vehicles, as well as individual components and sub-assemblies, via the integration of recycling criteria in the product development process. There are also a wide array of industry projects to improve recycling and recovery rates (Leone, 2000).

In terms of reducing the environmental burden associated with the use phase, manufacturers have made great strides in improving the resource and energy efficiency of vehicles. For example, mostly in response to European Union CAFE guidelines, the average fuel economy in many cars has improved (SMMT, 2001). Efforts to reduce the weight of some vehicles, as well as developments in direct injection technology have contributed to this trend.

In addressing the environmental problems associated with exhaust emissions, regulations such as the Zero Emission Vehicle (ZEV) mandate in California have motivated car makers to seek technological alternatives to the internal combustion (IC) engine. Initiatives such as the development of fuel cell powered engines, as well as continued research into the use of electric vehicles represent attempts to seek alternatives to prevailing powertrain technologies. In addition, some companies have devised hybrid engine technology in an effort to realise some environmental benefits whilst still offering consumers the security of an IC engine.

The examples above show that the automotive industry has, in a variety of ways, shown commitment to addressing the economic and environmental issues with which it is faced. In the UK at least, the car industry has been singled out as one of the more forward looking sectors in terms of developing sectoral strategies to meet sustainability objectives. However, even given such efforts, many of the real and perceived problems associated with the industry as a whole continue to occur. In an attempt to understand why this is so, it is helpful to investigate some of the underlying reasons in a practical and theoretical context.

Sustainable Business Models and System Innovation

As described earlier, the automotive industry has been fairly successful in achieving a variety of eco-efficiency gains. Improvements have been made in reducing the quantity and improving the quality of emissions from vehicles. Much progress has been made in reducing fuel consumption and increasing the fuel efficiency of the vehicle parc. There have also been reductions in the environmental impact of production processes through the implementation of clean technology, and the establishment of environmental management systems at individual manufacturing sites as well as throughout supply chains. In addition, there is growing evidence that manufacturers are considering the life-cycle environmental implications of car production, use and end-of-life management in the design of new vehicles and models.

In a purely economic sense, a combination of strategies such as global consolidation, platform sharing, outsourcing of non-core competencies and employment of financial incentives has ensured that most companies have maintained some form of economic viability.

However, even given these ongoing and large-scale efforts, the economic and environmental problems associated with the industry continue. Most companies still return very slim profit margins when compared to turnover and some (e.g. Fiat) have even incurred heavy losses in recent years. Emissions of CO₂ to the atmosphere as a consequence of car usage continue to rise, as do overall levels of fuel consumption. This situation has led a variety of commentators to suggest that, for a variety of reasons, the type of product, process and other improvements achieved by the companies might never be adequate enough to effect lasting long-term sustainability improvements in the industry.

Limitations of current approach

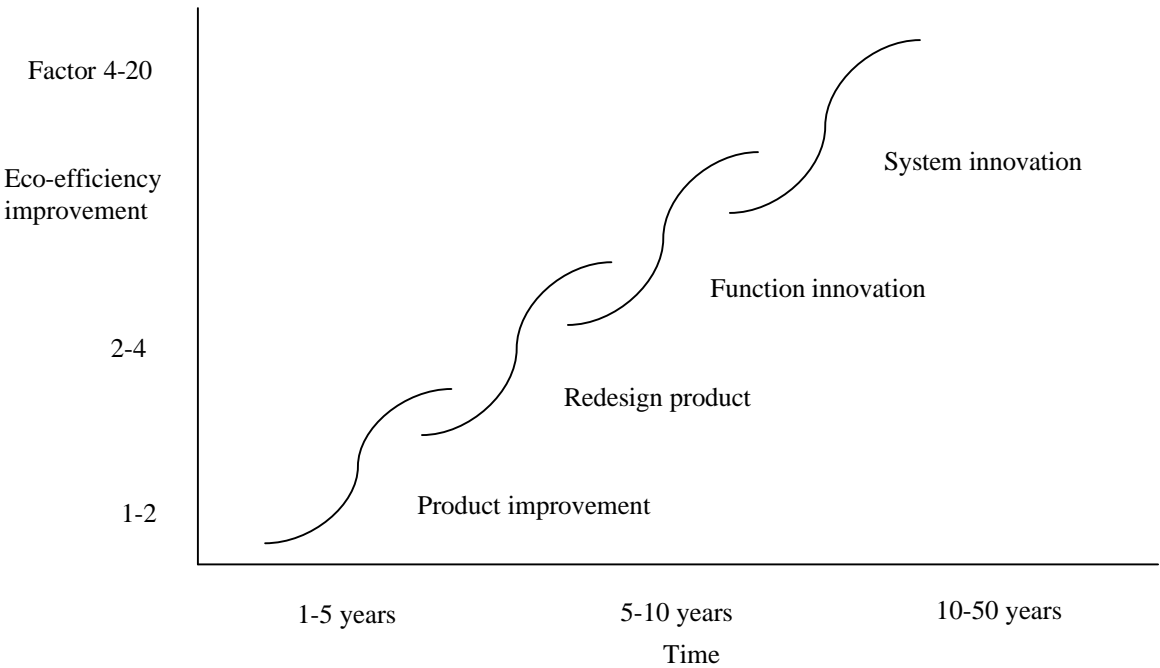
In terms of improving the profitability of the industry, the prevailing global system of vehicle production, based on the all-steel monocoque body, limits the scope of companies to adopt new strategies. The current paradigm drives the industry to manufacture the maximum amount of vehicles in the pursuit of economies of scale to recoup the investments made in capital intensive technology. The current economic strategies of most global automotive companies are based upon the reconfiguration of production and technological systems in order to realise maximum profits from the manufacture of cars based on the dominant design. However, such strategies do little to challenge the underlying logic of oversupply and inherent limits to profitability. It is clear that such a technocentric approach is at present unlikely to deliver radical improvements in economic prospects.

As far as the environmental domain is concerned, it has been observed that incremental improvements in the environmental performance of vehicles are often negatively counterbalanced by increases in overall consumption or more intensive usage patterns. In this respect, the prevailing economic strategy based on the maximisation of unit sales and consumption has a direct implication for the overall environmental impact of the industry. Eco-efficiency gains are more than offset by the fact that more cars are in use.

When these phenomena are taken into account, it is clear that a more integrated approach to economic and environmental strategies is required in order to achieve genuine sustainability gains. Such approaches will need to ensure that a wider array of stakeholders are involved in the required change processes. It has been recognised that on the basis of current thinking, it is unlikely that the major global automotive manufacturers can deliver sustainable mobility

solutions on the scale required. The limited focus on incremental technological improvements, however innovative, must be accompanied by a broader focus on elements such as behavioural and system-level changes (SustainAbility/UNEP, 2001, p29). The logic of these criticisms suggests that lasting change in the automotive industry can only be achieved via radical improvements in resource efficiency, accompanied by changing consumption patterns. The realisation of this inter-dependency between sustainable modes of production and consumption is closely linked to earlier theoretical models, which have suggested that, in the generic sense, change needs to be effected beyond the level of individual product improvements or even product eco-design and rather at the level of function and system innovation to achieve sustainability (Brezet, 1997). This is presented graphically in figure 1.

Figure 1 – Four levels of environmental innovation



Adapted from Brezet (1997)

The diagram shows that each wave builds upon previous gains in eco-efficiency, rather than on incremental technological advances. The first type of improvement occurs at the level of product re-design from the perspective of pollution prevention. This type of change is synonymous with 'end-of-pipe' environmental technology. In the automotive industry, the catalytic converter represents such a technology. The next level of environmental innovation is characterised by further improvements in product environmental performance. At this level, Life Cycle Assessment (LCA) techniques might be used to facilitate the identification of design options. Crucially, however, the underlying product concept remains unchanged. Examples of such approaches include the consideration of end-of-life management options in 'design for recycling' or 'design for disassembly' initiatives. The third type of improvement takes the underlying product function as the start point for an investigation of new and innovative ways to deliver this functionality. The final level requires changes in the entire system associated with the product. This may imply changes in the underlying economic or market dynamics as well as in infrastructure and the behaviour of related organisations and stakeholder groups.

At present, the type of improvements that might constitute level three or level four changes are not considered as part of the corporate strategies of the major manufacturers. However, it is in the context of this logic of function and system innovation that innovative new solutions must be sought to address the sustainability issues faced not just by the automotive industry, but by industry as a whole. It is also evident that in order to realise such solutions, a much wider array of stakeholders associated with a given product or industry must become actively involved in ongoing change processes. As well as collaborating with other organisations within its sector and throughout product supply chains, companies must now consider the role of consumers, retailers and other stakeholders outside their traditional sphere of influence to

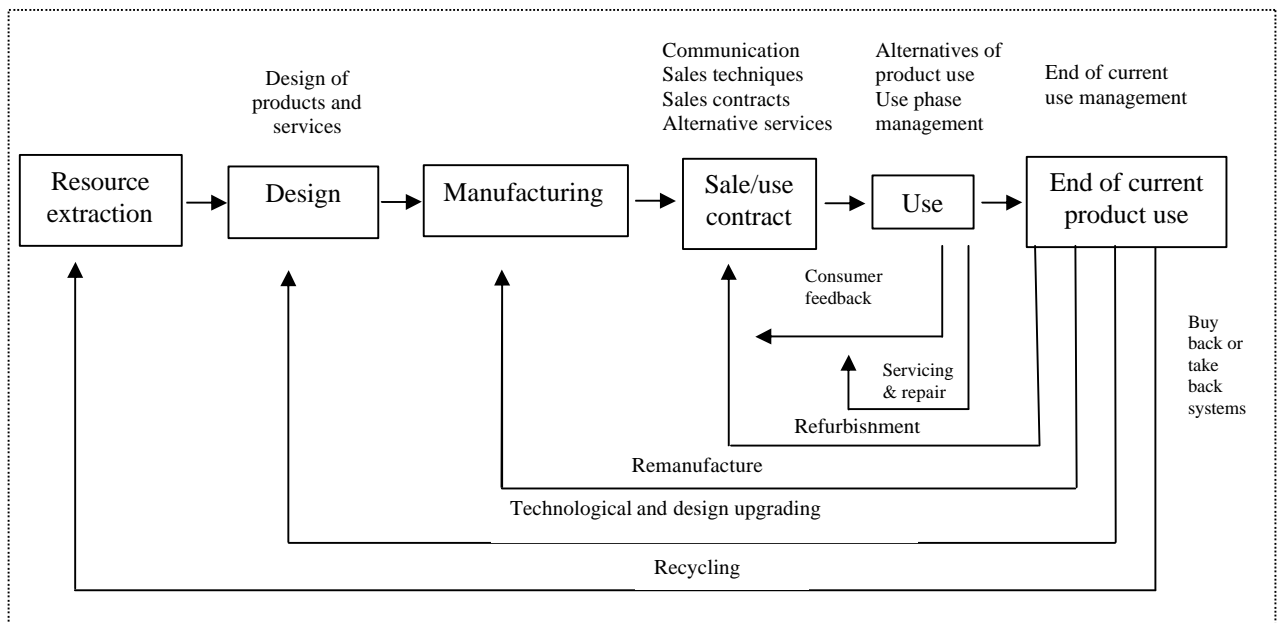
move towards the functional and systemic improvements necessary for sustainability. The challenge now is to devise ways in which such improvements might be achieved at the practical level. In this respect, the concept of product-service systems offers an interesting perspective.

Product Service Systems

A product-service system (PSS) has been described as ‘a pre-designed, marketable system of products, services, supporting infrastructure and necessary pre-arranged networks that can fulfil customer needs and, at the same time, minimise environmental impact’ (Mont, 2001, p123).

At its core, the PSS concept is based upon a fundamental shift in the relationship between the producers and the consumers of a product or service. Instead of being centred on ‘traditional’ forms of sale, ownership, consumption and disposal of products, a PSS focuses on the delivery of a ‘function’ to the customer that might in practice mean the provision of any combination of products and services that are be capable of ‘jointly fulfilling a users need’ (Goedkoop et al, 1999 p18). In doing so, it embraces a range of elements relating to the management of products throughout their life-cycle in an effort to minimise environmental impacts and to identify alternative profitable revenue streams. Figure 2 outlines the principle components of a PSS.

Figure 2 – Main elements of a PSS at the company level



Source – Mont, 2001

In practice, many of the elements of a PSS can and do form part of existing business to business or business to consumer interaction. However, it is only when each of the components are unified into a coherent whole that a ‘full’ PSS can be said to exist. These components are described in more detail below.

New notions of ownership

Within the prevailing production and consumption paradigm, the economic relationship between the manufacturer and ultimate consumer of a product is very limited. In most cases, once products leave manufacturing sites they are distributed to a network of retail outlets, where they are purchased by consumers. Following purchase, the responsibility for product use and disposal tends to lie with the consumer. Within this model, manufacturers have no further involvement with the management of a product following its sale. The intermediate retail function means that there is rarely any direct contact between producers and purchasers.

There are, of course, exceptions. Some companies sell their products directly to consumers via mail order or internet purchase. In addition, maintenance contracts or warranties sometimes oblige manufacturers, or their sub-contractors, to undertake repair activities if any faults occur to a product within a specified time-scale. In the main, however, consumers 'own' products after purchase and the responsibility of manufacturers is limited.

The advent of producer responsibility regulations in a number of regions has meant that manufacturers must now bear physical and often financial responsibility for the management of products at the end of their useful life. However, developments such as these do little to alter the fundamental nature of the economic relationship between producer and consumer. These types of regulations are aimed at improving the recovery, recycling and reuse rates of those products entering the waste stream. But since manufacturers are expected to finance collection schemes they can act as a disincentive for manufacturers to raise awareness of available routes for product recovery.

Within a PSS, a product is leased to a consumer instead of being sold. In such a way, the ownership of the product is retained by the manufacturer and utility is provided through the sale of functional units. This has the potential to radically change the behaviour of both manufacturers and consumers.

Design of Products and Services

The fact that manufacturers retain ownership of products within a PSS means that instead of representing profit centres, products instead become cost centres. Since producers become responsible for the physical and financial management of a product throughout its life-cycle,

they have an incentive to minimise the associated costs. For example, if manufacturers assume responsibility for product take-back systems, particularly when also subject to regulations that set targets on the percentage of waste products that are recycled or reused, they are motivated to explore ways of reducing the costs of managing the process and of recycling or refurbishing products at end-of-life.

This changed incentive structure has a number of implications for the way in which companies approach the design of products and services. To begin with, they will benefit financially by designing products that are easier, and therefore cheaper, to disassemble, refurbish or recycle after the initial use phase. In addition, manufacturers will be motivated to improve the durability of products in order to realise the maximum amount of revenue through using the minimum amount of resources. If the lifetime of a product is extended, more potential profit is available via the increased sale of 'functional units.'

Within this context, concepts such as the modularity and upgradeability of products become an important part of the design process. If individual components or 'modules' of a product can be regularly repaired, replaced or upgraded as part of an ongoing contract between producer and consumer, the concept of providing entirely new products and disposing of used ones becomes increasingly obsolete.

New forms of producer-consumer interaction

Another aspect of a PSS is the importance of new forms of dialogue between the supplier and the user of products and services. It is envisaged that such channels of communication will further improve the environmental benefits that might be attained. For example, in many product groups it is during the use phase that a significant proportion of negative

environmental impacts occur. As shown above, this is the case for a car, where CO₂ and other pollutants continue to be emitted throughout its life. However, the types of long-term producer-consumer relationships facilitated via a PSS present opportunities for the provision of information to users on how to minimise the environmental consequences of product use. The manufacturers of products are likely to possess better information on the conditions of usage under which such impacts might occur and, within a PSS, can provide users of products with guidance on how to best avoid such types of usage.

Another facet of producer-consumer interaction that might be facilitated within a PSS is the reverse flow of information relating to aspects of a products environmental performance. It is possible that, through long-term usage of a product or service, consumers might discover important facts relating to how best to reduce environmental impacts or improve design. Via formal feed-back loops, this information could be conveyed to manufacturers, and be considered as part of the ongoing process of continuous PSS design and improvement.

It is likely, at least within conventional modes of product manufacture, distribution and reuse, that retailers would form a pivotal role in facilitating such exchanges of information between producers and consumers. At the point of sale, retailers might provide users with information on environmentally optimised product use. They might also act as first point of contact for users when they make suggestions for product improvements intended for manufacturers.

The PSS concept represents an example of an innovative practical approach to moving beyond simple product environmental innovation and towards innovation at the functional and systemic level. The table below summarises some of the benefits and also the potential limitations of adopting such an approach.

Table 1 - Some benefits and limitations of product-service systems

Benefits	Possible Limitations
<i>Customer Relationship Management</i> - By entering into a contract with consumers, companies are provided with opportunities to communicate with them on a regular basis. Within a PSS this might entail the provision of information on new products, services or upgrades. New forms of producer-consumer interaction are also facilitated (see above).	<i>Over-reliance on existing infrastructure</i> - In order to function optimally, a PSS must often make use of existing infrastructures and networks. For example, the provision of product take-back systems might need to make use of existing collection services provided by local authorities or retailers or of the local recycling infrastructure. Such systems may face capacity constraints or lack appropriate technology.
<i>Product Acquisition</i> - The establishment of a system of regular product take-back for upgrades or replacement allows companies to benefit from a continuous and predictable source of materials and components.	<i>Negative environmental aspects of take-back and reverse logistics systems</i> - The establishment of product take-back systems may result in an increase in transport mileages and associated emissions, especially if producer and consumer locations are dispersed across large geographical areas.
<i>Environmental benefits</i> - Environmental improvements include dematerialisation; reduced impact during use phase via improved availability of information; regular upgrades to more environmentally benign technology; better end-of-life management of waste; and, provision of economic incentives to reuse, repair and re-manufacture.	<i>Management of retailer function</i> - The central role of retail and sales staff in liaising between producers and consumers and facilitating flows of information may be difficult to manage in practice.
<i>Legislative Compliance</i> - A PSS approach assists manufacturers in meeting obligations for the collection and treatment of waste products (e.g. as imposed by the EU WEEE and ELV Directives).	<i>Company related barriers</i> - These include an unwillingness to divulge technical information or outsource support functions; internal systems inertia (e.g. accounting methods); capacity constraints; cost; internal conflict of functions

(Adapted from Mont, 2001, pp20-25)

It is possible that the adoption of the PSS concept within sectors of the automotive industry could represent an interesting and effective means of addressing some of the economic and environmental concerns outlined earlier. However, although there are numerous examples of initiatives that concentrate on one or more elements of a PSS (e.g. car sharing or vehicle

leasing), there are currently no examples of what could be said to constitute a ‘full’ PSS within the industry. It is therefore difficult to assess whether the type of economic and environmental benefits that might accrue from such a system-level change can be realised at the empirical level. The following section investigates the possibility that the creation of micro-factory retailing sites might facilitate the establishment of a series of complete product-service systems in the industry, thus allowing the full range of economic and environmental benefits to be achieved.

Micro Factory Retailing in the Automotive Industry

As mentioned earlier, the core technology of most of today’s automobiles is the all-steel monocoque body. The production technology required to manufacture these bodies is highly capital intensive and forces businesses to make large volumes of cars in order to achieve economies of scale and recoup initial investments. The result is the prevailing market structure, characterised by large scale manufacturing plants tied in to global distribution and logistics systems as well as the host of associated economic and environmental problems.

The Micro-Factory Retailing (MFR) concept is founded on the idea that the all-steel body vehicle design is replaced by one based on a separate chassis, onto which a variety of different body shapes may be mounted. The production technology associated with this type of design is much lower than that needed for the monocoque body. It is therefore possible to break-even, or to achieve a profit via greatly reduced manufacturing volumes (Wells & Nieuwenhuis, 2001). This departure from the prevailing manufacturing paradigm allows increased flexibility in areas such as plant-size, location and function as well as in vehicle design and relationships with consumers. In many ways, the MFR concept is closely aligned with many of the ideas associated with PSS. Furthermore it might also represent a means of

delivering such a system in the automotive industry that is capable of addressing some of the potential limitations outlined earlier (see Table 1). This idea is explored in more detail below.

Plant-size and location

The fact that high manufacturing volumes are no longer economically necessary within the MFR system means that there is more scope to experiment with the size and capacity of individual production sites. Break-even points can be achieved at an order of magnitude lower than is currently possible, meaning that an average MFR site is more likely to produce around 5000 units per annum rather than 250,000. The smaller scale of manufacturing operations means that plants can be located much closer to the market than is currently possible, without the need to occupy large areas of land, or be linked to extensive distribution systems. In fact, MFR sites might be based at the local level, thus doing away with the need for comprehensive distribution systems altogether. Similarly, although more generic components and sub-assemblies could be sourced from central locations, operating to economies of scale, there might be a greater capacity to source other parts and materials locally. It would be more economically and environmentally efficient to supply components via logistics systems as opposed to entire vehicles.

Innovative Vehicle Design

Freedom from the constraints of the all-steel body means that manufacturers would have the capacity to be more experimental in their approach to vehicle design. In practice, the separation of body from chassis provides opportunities for the introduction of modular concepts. This opportunity is further enhanced if the chassis is based on alternative powertrain technology such as electric or fuel cell. In theory, components, sub-assemblies, body panels or even an entire body could be easily removed and repaired or upgraded with

relative ease. Examples of vehicles based on such modular designs already exist (Modular paper). In addition, concepts such as the Ridek system show that interchangeability between a variety of body shapes and chassis designs is a realistic aim (Dower, 2001; Wells, 2003). This possibility means that an MFR site would be in a position to produce such vehicles as the central element of a PSS. Furthermore, it would be possible for users to use a vehicle with an electric or fuel cell based powertrain for urban travel and easily change to an IC powertrain for inter-urban journeys while still keeping the same body and interior. Such an arrangement means that infrastructural limitations to the use of hydrogen or electric based vehicles could be overcome incrementally through initial provision of recharging or refuelling facilities at the local level, allowing a phased transition from a solely petroleum based system.

Plant-function

The small-scale and locally-based nature of a typical MFR site means that it would not be limited solely to carrying out manufacturing activities. Proximity to the market means that facilities could also perform a retail function. It is possible that consumers could visit an MFR site and, together with qualified manufacturing or design staff, specify the exact nature of the vehicle they require. They could then collect the car from the site when it is finished.

Such a set up offers much more choice for consumers over vehicle design and specification. Crucially, the arrangement also facilitates the type of enhanced producer-consumer interaction envisaged as part of a PSS. In addition, such communication processes can occur without the need to involve independent or franchised dealerships or retailers. Users have direct access to qualified staff involved in the design and manufacture of vehicles and *vice versa*.

All of the above factors combined mean that an MFR site is ideally placed to offer a full repair and modular upgrading service on vehicles leased to consumers as part of a long-term contract. Within such a system, it is likely that the type of vehicles produced would continue in usage beyond currently viable mechanical or economic limits. In fact, it is possible that many would never become end-of-life vehicles in the ‘traditional’ sense. However, localised MFR sites would still be capable of managing take-back and reverse logistics systems that handled complete vehicles, modules or components for servicing, repair, upgrades or end-of-life management. Particularly when based in urban locations, a micro-factory’s proximity to consumers would also mean that some of the economic and environmental shortcomings of such systems could be overcome.

Advantages of the MFR approach for establishing a PSS in the automotive industry

The variety of elements associated with an MFR approach to vehicle manufacture and producer-consumer interaction demonstrate that it could represent a viable option for the introduction of PSS concepts in the car industry. Moreover, such an approach also has the potential to address some of the potential limitations to a PSS as outlined in Table 1 and facilitate a transition towards sustainability through system-level innovation. The list of points below summarise the possible advantages.

- The fact that a single facility manufactures finished goods and provides a package of services means that incentives for sustainable product and service design may be increased.
- MFR sites would re-unite the commerce and manufacturing function, which have grown separate in the course of the spread of mass production. Such an approach would redirect production towards customer needs, rather than following the logics of

mass production (Jackson, 1996). In this respect, MFR is closely aligned with notions of a 'customized economy' (Schmidt-Bleek & Lehrner 1999).

- The possibility of conflicting objectives between the manufacturing and service divisions of the same company is reduced (White 1999).
- The new manufacturing and retail paradigm brings consumers closer to manufacturers. This means there is more opportunity to facilitate the type of consumer-producer information feedback loops envisaged by the PSS concept.
- Proximity of sites to users means that the operation of reverse logistics and product take-back systems is likely to be more economically and environmentally sustainable. Reduced mileages mean that less expenditure on energy is required. In addition, associated emissions will be reduced, or even eradicated if collection vehicles incorporate environmentally benign powertrain technology.
- The combination of leasing options and regular product upgrades facilitates efficient planning of product, component and material acquisition via reverse channels (Heiskanen & Jalas, 2000, p28).
- In the long term, the manufacture of vehicles based on the MFR concept would lead to better eco-efficiency of production and eco-sufficiency of use. Manufacturing volumes and resource usage would decrease and there would be less negative environmental impact during the use phase of the vehicle. In addition, there is likely to be a lower total stock of products and a higher rate and quality of utilization of end-of-life vehicles, components and modular sub-assemblies (see, Heiskanen & Jalas, 2000, p26-27; Stahel, 1996; Scholl et al., 1998; White et al., 1999; Littig, 1999).
- MFR facilitates the selection of goods more suitable for mobility needs than arrangements based on sales and ownership. This would be particularly evident via the possibility of using a chassis based on electric or fuel cell technology for urban

usage and conventional IC technology for larger journeys. In addition, a body-chassis division and inter-changeability means, for example, that a light and energy-efficient 2-seater body could be fitted for everyday usage, but a larger body with more storage or seating space could be leased when required and easily attached to the existing chassis.

- Body-chassis separation and localisation may also allow possibility of overcoming problems of infrastructure provision through the incremental introduction of recharging facilities or hydrogen refuelling stations at local levels while allowing inter-urban transport to remain under current infrastructure via use of IC chassis.
- The approach represents a potentially profitable and proactive means of responding to current and emerging patterns of public policy such as extended producer responsibility regulations and product life-cycle oriented legislation.
- The incentive to dematerialise, extend product life and improve product function is maximised when product function becomes more important than the physical product.
- Leasing options improve accessibility to innovative mobility options for poorer socio-economic groups.
- Reduced dependency on high capital intensity production technology improves prospects for improved profit margins at greatly reduced output levels.
- Freedom from the necessity to recoup high capital investment through the sale of a high volume of vehicles or models based on similar design allows greater flexibility to explore less conservative design options.

Directions for Future Research

The above analysis has shown that, at the theoretical level, the MFR concept facilitates the adoption of a full scale PSS at local levels. Furthermore, via aspects such as the unification of

the commerce and manufacturing function, and a reduced reliance on existing infrastructures, the MFR approach may also offer distinct advantages compared with prevailing visions of PSS. The key challenge now is to develop methods to evaluate the full sustainability implications of the adoption of such systems in comparison with the prevailing paradigm. It is also important to investigate the means by which such systems could be introduced within the automotive industry at the empirical level.

Evaluating the MFR and PSS Concepts

Earlier research has attempted to evaluate PSS alternatives in terms of their contribution towards sustainable development. Omann (2003) developed a multi-criteria tool and used it to compare PSS initiatives with existing ‘conventional’ products in eleven Austrian companies.

Table 2 summarises the criteria used in the evaluation process.

Table 2 - Criteria for evaluating sustainability effects of PSS

Dimension	Subgroups
<i>Economic Dimension</i>	Company key figures, product related figures, macroeconomic figures, stakeholder relations.
<i>Environmental Dimension</i>	Resource and material input, energy use, water use, land use, transport, waste, effluent, emissions, environmental management.
<i>Social Dimension</i>	Employee structure, social management, health and safety, social justice, equal opportunities, gender issues, human dignity, international justice, customers.

(Adapted from Omann, 2003, p13)

The results of the exercise demonstrated that the tool was an effective means of identifying barriers to the establishment of PSS. In addition, it provided evidence that trade-offs often exist in terms of sustainable development, but are less apparent in terms of the development of eco-efficient alternatives. The study also identified several important challenges for the further development of multi-level evaluation tools. These relate to the need for more robust methods of measuring criteria (especially relating to social sustainability), comparing PSS alternatives against reference products, avoiding bias in the weighting of variables, and avoiding mathematical weaknesses.

Goedkoop *et al* (1999) developed a combination of qualitative and quantitative methods to evaluate a variety of PSS approaches throughout the world. In terms of qualitative assessment, they developed an approach based on four axes addressing the following aspects:

- Environmental characteristics at the level of function fulfilment and their relationship to the overall environmental load on society;
- Economic characteristics at the company level and at the business sector level;
- The extent to which the PSS is aligned with a company's identity and strategy; and,
- The extent to which the market will accept the PSS.

In terms of the process of assessing each of the above criteria, the research team advocates the use of an expert panel to compensate for the lack of quantitative data. These experts discuss and evaluate a PSS on each axis in comparison to a reference, before offering a final assessment. As far as, quantitative assessment is concerned, the study develops a method of analysing the first two axes using an E2 (Economy-Environment) vector, based on an adaptation of an LCA based eco-pool graph. This vector is used to assess the decoupling of economic value and environmental impact via PSS.

This approach again demonstrates the difficulty of developing robust methods to address variables such as consumer acceptance since ‘emotion, experience and instinct play an important role ... [and they] are virtually impossible to quantify’ (*Ibid.*, p39).

The Product Service Systems Methodology (MEPSS) (www.pss-info.com) is another initiative that seeks to develop a methodology to analyse newly developed PSS. Here, the aim is to provide industry with a toolkit to evaluate PSS alternatives in terms of:

- design and implementation aspects;
- micro-, meso- and macro-economic impacts;
- social and environmental impacts and issues related to consumer acceptance and culture and ethics.

It will be interesting to observe the approach adopted by this ongoing initiative in addressing some of the challenges of assessment identified in the earlier studies.

A final initiative is also aiming to assess the performance of PSS solutions against existing offerings based on a variety of economic, social and environmental criteria (www-mmd.eng.cam.ac.uk). Factors considered include, sensitivity of performance to household size, density of user-base, scale of production, the technical details of implementation and the likely impact of rebound effects.

The approaches outlined here demonstrate the range of possible options for evaluating the sustainability impacts of PSS initiatives. The research shows that the development of methods to assess the relative merits of different PSS initiatives is subject to several key

challenges. It appears that means of identifying and quantifying the eco-efficiency aspects of PSS in terms of the absolute or relative decoupling of economic growth from environmental burden are easier to devise than more nebulous aspects such as consumer acceptance. In terms of assessing the full raft of sustainability effects, it is therefore vital to continue the development of robust methods of evaluating the ‘social’ impact of PSS and MFR. In terms of research focusing on the specific merits of using the MFR approach to introduce PSS concepts, it is also important to ensure that future initiatives assess the particular effect that localisation and the unification of manufacturing and retail functions might have on overall sustainability impacts.

Developing a Methodology for Implementing MFR and PSS

As well as continuing research into the evaluation of the MFR approach to introducing PSS in the automotive industry, another key challenge is to devise methodologies to facilitate the introduction of such systems at the empirical level.

Mont (2001) has suggested such a methodology for working with companies on developing a PSS. It is based on step-by-step approach with several distinct phases. These include:

- *Initial review* - where existing activities within a company that might underpin a PSS are identified, in tandem with the development of necessary functions and expertise;
- *Marketing analysis* - which accounts for customers’ needs in the developing of a system as a means of ensuring maximum satisfaction;
- *Feasibility analysis* - where a cost and benefit analysis is carried out of the various steps required to introduce a PSS in order to choose the most efficient in terms of resource consumption and results obtained;

- *Implementation* - including the development and testing of products and services on a limited market in order that key aspects might be corrected and refined;
- *Continuous system development* - which involves the addition of new elements of the PSS according to criteria of economic, social and environmental sustainability.

The methodology also identifies critical success factors such as consumer perception of trust in the function provider, constant feedback concerning system function, changing customer needs, necessary changes in the system and the establishment of long-term relationships between producers and consumers.

Goedkoop et al (1999) advise that, in order to explore PSS concepts in more detail, pilot projects should be carried out. These pilots should focus on the twin goals of verifying the concepts and tools developed and demonstrating the possibilities of PSS to businesses and society. It is suggested that the pilots are facilitated via government backing, in co-operation with companies and industrial associations.

A further interesting alternative for facilitating the introduction of MFR and PSS concepts is the tool of strategic niche management (SNM) (Hoogma *et al*, 2002). SNM refers to the management of a process of technological and/or market niche creation, development and breakdown to enable regime shifts (*Ibid*, p30). This approach stresses the importance of factors such as higher order learning and institutional embeddedness in evaluating the success of niche development. In terms of learning, the following aspects are important:

- Technological development and infrastructure, including complementary technology and infrastructure needed;

- Development of user context, including user characteristics and requirements;
- Societal and environmental impact;
- Required Industrial development network needed to widen diffusion;
- Knowledge concerning the associated government policy and regulatory framework and government's role in the introduction process.

An integral aspect of the required learning processes is the need to ensure co-evolutionary dynamics, that is the 'mutual articulation and interaction of technological choices, demand and possible regulatory options' (*Ibid*, p29).

As far as the institutional embeddedness of niche options is concerned, three crucial factors are identified:

- Incorporation and increased awareness of complementary technologies and necessary infrastructures;
- Establishment of widely shared expectations; and,
- The enlisting of a broad array of actors aligned in support of the new regime.

System innovations such as MFR and PSS require awareness of the importance of network and infrastructural factors, as well as the involvement of a wide range of stakeholders in change processes.

Conclusion

The analysis throughout this paper has demonstrated that the adoption of an MFR approach may provide a credible opportunity to bring about system-level innovation in the automotive

industry. However, it is clear that there is a need to test this thesis through a rigorous evaluation of the likely sustainability impacts of the visualised change processes. In addition, such radical changes present considerable challenges to a wide range of actors both within and outside the industry to enable success at the practical level.

It is also clear that in order to realise the full range of possible sustainability improvements, a number of related developments at the level of the entire economy are of importance. For example, the full environmental benefits of electric powertrain technology can only be achieved if the necessary electricity is produced from renewable sources. Earlier research has established the theoretical framework for such broad system-level requirements (Nieuwenhuis, 2002).

The challenge now is to engage the relevant stakeholders in an ongoing process of research, evaluation and testing, at both the theoretical and practical level, in order to foster the levels of commitment and expertise necessary to effect real change in the industry. In this respect there are important roles for industrial actors, as well governments, users and a broad range of associated interests.

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