3DAYCAR PROGRAMME

Production and Process Technology:

The Impact of Vehicle Design on Rapid Build to Order

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Executive Summary

Vehicle design is vital to the ability to achieve a 3DayCar in terms of ensuring the flexibility of componentry to enable mass customisation in a short lead time. The objective is to utilise the minimum variety of specification in design for production to satisfy the greatest number of customer specifications in the market place. This mainly involves the minimisation of the number of body variants, including paint, entering the vehicle assembly line and the standardisation of componentry assembled on the line. These allow vehicles to be produced in the shortest time from identification with the customer order, at the lowest cost.

The industry has been moving strongly in the direction of standardisation in order to reduce costs. However, any such movement must consider whether the standardisation is affecting:

- Brand differentiation and the ability to maintain price differentials in the marketplace. Therefore componentry must be divided into brand differentiators and commodities, and only commodities fully standardised.
- The relationship between the vehicle producer and the components supplier. Standardisation in the areas of modules, in particular, has been moving value added and knowledge architecture to component suppliers and caused concerns with some vehicle producers over the affect on their power in the supply chain

This research examines the technological opportunities for rapid build-to-order (BTO) in current and future vehicle design over the next decade, taking into account the above factors. It highlights the significance of vehicle complexity and variety, in terms of reducing order-to-delivery (OTD) leadtime by component reduction, sharing / standardisation and mass customisation. Investigation into specific aspects of vehicle design reveals the following:

Body construction

- The platform concept is based on standardised components, offering the potential for a combination of high model variety with comparatively low levels of complexity. Platforms can benefit 3DC because they can share components across models and brands, (e.g. Ford, Jaguar and Volvo) increasing flexibility, product mix and capacity.
- Alternative methods of body construction to the traditional monocoque increase the total number of structural body parts per vehicle. This is contrary to 3DC’s requirements for minimum complexity. However, if these parts can be shared across model variants and platforms and be more easily adaptable to product change this can reduce complexity and cost overall.
- The ‘Independent Body and Panels’ (IBP) approach de-couples paint from vehicle production. Exterior panels can be painted separately from the vehicle body, as in the case of the GM Saturn EV-1. Another example of this is the use of thermoplastic panels on the DC Smart, Hambach, where in-moulded colour means that the paint shop and surface quality / reliability issues are removed from the line.
- Other examples of body construction technology that can potentially enhance 3DC vehicle design include: thermoplastic body panels, vacuum pressure aluminium die-casting, glazed roof panels / painted roof modules and hydro-forming.
- Alternative methods of body construction can redefine the current limits of platform sharing. Common platform elements that have no impact on the vehicle’s outer skin can be retained, whilst an almost infinite variety of new model shapes are possible from a basic kit of modular, structural

components. This goes some way towards addressing the 3DC challenge: achieving mass customisation through minimising complexity and adopting an integrated approach to parts sharing.

Powertrain

- A greater proportion of internal combustion (IC) engines will be direct injection (DI) diesel engines by 2010. However, competencies related to traditional powertrain development will remain with manufacturers, albeit with greater collaboration with suppliers.
- Hybrid vehicles are the most likely short to medium term solution to 21st century personal transportation. However, the dual powertrain design represents a challenge to 3DC, which is seeking ways to reduce internal vehicle complexity.
- In the longer term, 10 to 20 years, there will be growth in the variance of powertrain, for example Fuel Cells and Electric vehicles. Whilst focusing on one source of power, this will require different body, transmission, gearing and suspension requirements. These developments are unlikely to have a significant impact over the next 10 years in terms of the proportion of total vehicles produced.

Modules

- Modules benefit 3DC by reducing vehicle complexity in design and by removing complex assembly procedures from production. Minimising internal vehicle complexity enables a BTO strategy by reducing inventories and assembly leadtime. However, this means that much of the responsibility for delivery and stocking is passed back up the supply chain.
- The benefit of modularisation is derived from the concept of ‘sharing’ component assemblies, either internally within the vehicle or externally across individual models and brands. However, a disadvantage of sharing and standardisation is the danger of losing the distinctive ‘look and feel’ of individual models.
- Whilst the current emphasis in vehicle design is on module *integration,* which suggests that they may become more model specific, this conflicts with the generally accepted notion that industry should increase parts sharing and *standardisation.*
- Current plans to introduce painted door modules, interior modules and roof modules will significantly reduce production leadtime. This can be achieved only by VM’s forming close partnerships with 1st tier suppliers. The roof module is particularly relevant to 3DC as it eliminates the sunroof option during the early stages of production in BIW, and postpones it until final assembly.

Electronics

- The increase in development of telematics and mechatronics suggests that cars will become more complex. It is expected that 90% of the basic functionality of future innovations in cars will be determined by electronics. However, by integrating software and assembling electronic components before the ‘3 day clock’ commences, the problems of complexity can be overcome.
- Multiplex (MUX) represents a key enabler to 3DC where, a single optical fibre with Controller Area Network technology (CAN), eliminates hundreds of variations of traditional wiring harnesses. MUX potentially allows electronic options to be added during production, at the dealership or at any stage during the vehicle lifecycle.
- X-by-wire technology for braking and steering can potentially reduce internal complexity through electronic control. Its benefit to 3DC is that less mechanical parts are required, such as hydraulic

cylinders, brake lines and fluid. However, the first systems will retain a hydraulic back-up. Complete electromechanical systems are not expected for between 8 to 10 years.

- Whilst microprocessor and electronic control units (ECU) content per vehicle is expected to increase, this is not expected to significantly affect complexity, as it is the programming of the software inside the units that determines specific functional characteristics. Vehicle electronics may offer the potential for every vehicle to be high specification, but with only selected features activated at the last possible moment before delivery.
- Whilst the concept of 'plug and play' of remote electrical options is now technically feasible with MUX and CAN, this poses a number of issues over costs of warranty and installation. The ability to retain the current price differentials between options which become plug and play, and therefore profit potential, must be questioned and thus careful implementation employed.

Design for Recyclability

- DFR can reduce part counts and drive simpler designs, for example by commonising materials used by bumpers and cockpits.
- Composites and in-mould coverings make vehicle assembly easier, but will conflict with recycling unless totally compatible materials are used.
- Recycled material is now equal to virgin material in quality and cost, but the market tends to be more volatile in terms of price and supply. Quantities of recycled material used in cars are currently low, but greater volume will reduce supply volatility. However, the risk to lean material supply will still exist.

Cost

- When considering adopting new technology, the following factors must be considered as well as variable costs in terms of maximising product line profitability:

  - The saving in vehicle stock associated costs in the market place by enabling true BTO with minimum delay and maximum mix flexibility.

  - The cost of investment for product change.

  - The investment in plant and effect on fixed costs.
- The potential benefits of individual vehicle design technologies such as modular frame technology and plastic panels are an example of looking at all aspects of cost, since they may increase variable unit costs, but can significantly reduce the cost of product change and increase the effective life span of certain types of machinery.

  They are also potential enablers to a 3DayCar with minimum finished vehicle stock where savings of the order of 6-10% of the vehicle price have been quantified by ICDP.

This research shows that specific areas of vehicle design, such as body construction, are fundamental to the entire process of vehicle assembly. It develops the existing work on spaceframes, adding independent body and panels (IBP) as a significant construction classification.

There are strong links between complexity and the development of platforms and modules. A rapid BTO environment is enabled by common platform strategies, which increase parts sharing across models and brands. Modules, the basic unit of the platform concept, will benefit 3DC by removing complex assemblies from the line, thus also reducing production leadtime. However, responsibility for delivery and holding stocks is shifted towards suppliers. The roof module is particularly relevant to 3DC as it eliminates the sunroof option at BIW. Current concepts for painted door and interior modules will become common practice for many manufacturers, who may offer a ‘mix and match’ service for customers.

Despite concerns raised here over brand differentiation and the ability to maintain price differentials, in the future, vehicle differentiation will be defined more by electronics than mechanical functions contained in the vehicle. The growing presence of electrical enablers such as MUX, CAN & X-by-wire will provide a rich source of mass customisation, offering the flexibility of ‘plug and play’ for new products and services. Together with independent body panels, this could lead to new concepts such as vehicle ‘refreshing’, which will extend lifecycle and maximise profit opportunity.

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1 Introduction

1.1 Overview

This report reviews current and future vehicle design in terms of the implications of reducing order to delivery (OTD) leadtime. It examines the capability of vehicle technology to provide a responsive manufacturing strategy and achieve rapid build to order (BTO).

Vehicle design refers to the attributes of the product itself rather than the processes such as new product development (NPD), although specific areas of the process may be of interest, such as 'ramping up' new products into existing production.

This is the first of two studies under the collective title of 'Production and Process Technology'. In the context of overall 3Daycar (3DC) research output, the 'Vehicle Design' report is positioned as per Figure 1:

Fig. 1 Technology research

Current Vehicle Assembly Technology
'The Paint Shop' (January 2000)
'Spaceframes' (January 2000)

Information Technology
'Current IT Systems Barriers' (July 2000)
'Future IT for 3Daycar'

Production and Process Technology
'Vehicle Design' (December 2000)
'Cells, Lines and Tooling'

1.2 Aims and Objectives

The overall objective of this research is to examine the *technical opportunities* for reducing OTD leadtime.

A major inhibitor to OTD is complexity, both in terms of *internal* production technical complexity and *external* customer product variety. Minimising these two factors will increase the VM's ability to move towards a flexible production system and ultimately a build to order strategy (Holweg, 2000)[1]. There is wide literature coverage concerning the trade-off relationship existing between complexity, variety and manufacturing efficiency (Batchelor, 2000).[2] This report however, will concentrate on product complexity based approaches such as component standardisation, modular design concepts and product platforms, rather than process based approaches such as of flexible production strategies, which are covered in the 'Cells, Lines and Tooling' report.

The concept of 'mass customisation' is also significant to 3Daycar (3DC). It aims at the traditionally contradictory goals of mass production and mass customisation products, ideally produced at low cost but with high variety. J. Pine's (1993) articulation of the types of mass customisation includes modularity, involving assembly to order from modules and component sharing across product platforms. The links between vehicle design, complexity and mass customisation will be examined throughout this report.

[1] Holweg (2000) 'The Order Fulfilment Process in the Automotive Industry'

[2] See also: Skinner (1974), MacDuffie (1996), Jugens (1997)

Achieving a BTO strategy for 3DC will therefore require the following:

- Minimum internal technical complexity (e g *modularity, component sharing, platforms*).but maximum external variety for the customer
- Minimum complexity in body types entering the vehicle assembly line
- Minimum stocking costs.
- Maximum number of 1st tier components that can be produced for assembly in under 2 days.

1.3 Assumptions

The research will build on the conclusions from the 1st year 3DayCar research:

- 'The number of major 1st tier components in terms of value that can be produced and delivered for vehicle assembly in less than 2 days must be maximised to minimise the stocking cost of 3Daycar.'
- 'Late configuration in the market place not only reduces production complexity, it also ensures the shortest leadtime to obtain more specification choice'.
- 'The prime requirement of vehicle assembly is flexibility. Assembly time on the track is of the order of 6-8 hours and will be reduced significantly only by changes in the structure of components. Flexibility in terms of components implies modularisation, particularly switch on / off options and standardisation across derivatives and models.'
- 'The design of a vehicle for the 3DayCar must take into account not only the need for fast assembly and late configuration, but also ease of disassembly and viable recycling costs.'

Therefore, the key research question is:

> **What are the key technological opportunities in current vehicle design, to 2010, for achieving rapid BTO ?**

1.4 The Overall Context of Vehicle Design

Other than the basics of quality and reliability over an acceptable vehicle life span, the main drivers of vehicle design are:

- **Brand differentiation**: The maintenance or innovation of specific characteristics that define the brand. The establishment of a strong brand is a determinant of the size of the profit 'cake' available to all the players in the supply chain.
- **Power**: The retention of knowledge architecture and value-added activity by the vehicle manufacturer leads to the maintenance of their power in the supply chain. In essence, this determines how much of the 'profit' cake the manufacturer obtains. However, if the manufacturer abuses this power, then the size of the cake is smaller, because other players cannot invest sufficiently in the future.
- **Cost**: The ever increasing pressure to reduce cost as the total profit cake diminishes.
- **Legislative**: The requirement to meet environmental and safety legislation so that there is potential for a profit cake.

The major driver for some time has been cost. This has taken two directions:

- Standardisation in terms of floor pans, components and modularisation
- Reduction in new product development costs. This is not only through using common componentry but also by introducing flexibility in machinery and product design so that the cost of product change is minimised. Sometimes increased production costs are accepted to achieve lower development costs, although this may also be influenced by legislative requirements. For example, future fuel efficiency targets drive lighter body constructions, which are more expensive to produce than conventional monocoque bodies, but potentially reduce product change costs.

These developments are beginning to impact on other drivers of vehicle design:

- The customer can realise that the componentry in two different brands of car under the umbrella of the same organisation are very similar, and purchase the lower rather than higher price brand. This reduces the previous brand price differential potential and thus overall profit.
- Toyota have stated that they will not outsource modules because it causes them to lose power (as well as knowledge architecture on such areas of the vehicle). Component suppliers have been growing in size as well as in their value-added content of the total vehicle for some years and are threatening the power relationship with the manufacturer.

Therefore, there is a need to question the movement towards standardisation and modularisation. Manufacturers must determine which areas of the vehicle are:

- Key brand differentiators; which must be distinctive and, if relating to a module, preferably retained in-house
- Not important to brand; which can become standardised commodities

Vehicle design must proceed from this distinction.

At the same time, development in component machinery must be taken into account. This is moving towards much more flexibility to product change and, therefore, to producing small batches with short changeover times. For instance, transfer lines are being replaced by small machine cells. Standardised commodity components can be produced most cost effectively on transfer lines (and can be sold over trade auctions on the Internet!), whereas brand differentiators need small machine cells. With development being concentrated on machine cells, more brand differentiator components can be produced cost efficiently in the future. It is likely, therefore, that eventually the trend towards component standardisation will be reversed.

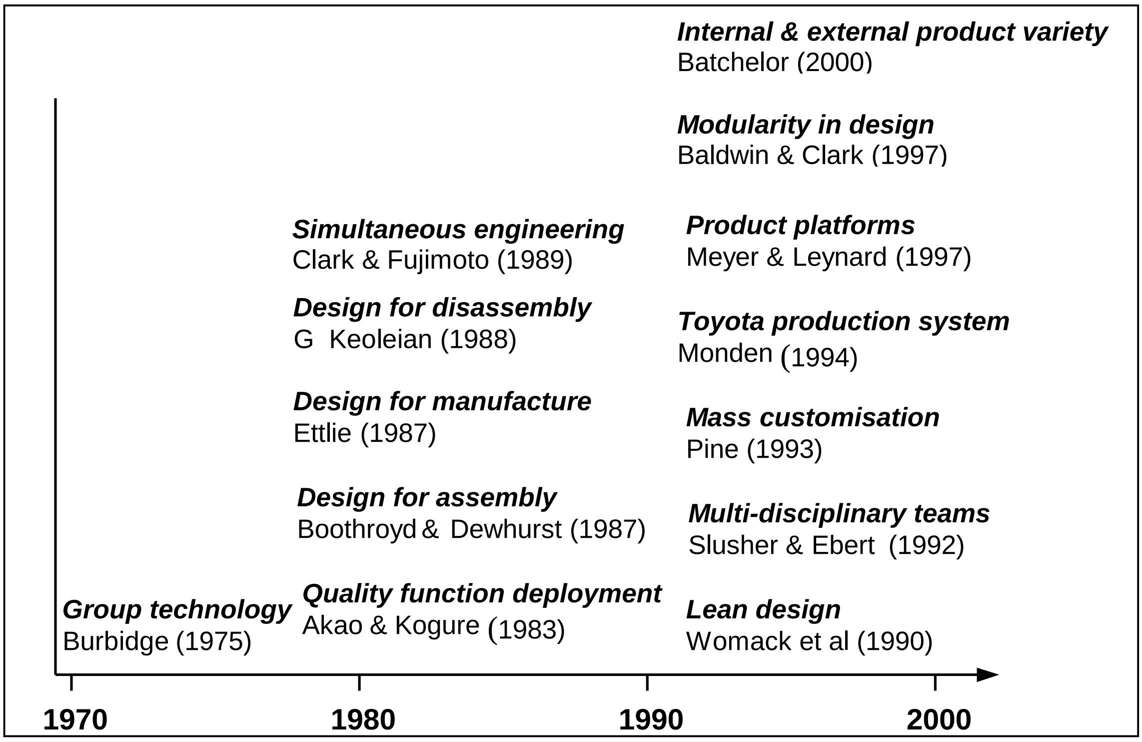
1.5 Design for industry: the relevance to 3DC

The integration of product or ‘industrial’ design into manufacturing has been slow in comparison with other disciplines such as production engineering. However, from the 1970’s onwards it has developed rapidly into a number of key tools and concepts, many of which come from the automotive industry. Figure 2 provides a review of the origins of design in manufacturing and how it has developed, encompassing methodologies for component assembly, NPD, Lean, Teamwork and a number of key 3DC concepts described earlier in this chapter. The following is a brief summary of some of these concepts and their relevance to 3DC and rapid BTO.

Group Technology (GT) is the production of a ‘part family’, comprising all the necessary machines and processes, enabling *one piece flow* and large reductions in leadtime and inventory. GT goes beyond the concept of cellular manufacturing in that it is central to achieving JIT: aiming for flexibility, responsiveness, visibility, high quality, minimal inventory and focus.

Design for Assembly (DFA) is a systematic analysis process intended to reduce the assembly cost of a product by simplifying the product design (to make componentry easy to assemble) and reducing the number of parts involved.

Figure 2 Product design: tools and concepts 1970 – 2000



Design for manufacturing (DFM) is a key enabling concept for lean manufacture. *'Easy and fast assembly'* has an impact right through the manufacturing life of the product, which requires early, collaborative input from both Design and Manufacturing functions. DFM should also include the cost of components, assembly and support systems.

Lean design is the early confrontation of conflict in design trade-offs. Womack (1990) found that in the West the number of design changes peaks at the time the product goes into production when difficult decisions can be delayed no longer. In Japan they are highest near the beginning of the design process. The best lean projects have the highest number of people involved from the outset with all relevant specialities present. Late design changes throw an enormous strain on the relationship between design and manufacturing. A number of procedures can be used: establishing a sound definition of the project at the outset, restricting design innovations to proven technology[1] and the use of interdisciplinary teams in simultaneous engineering.

Product platforms is a design from which many different derivative products can be launched, often over a period of time. These products or models share common components, modules and manufacturing methods. Significant cost savings are achieved in NPD, staff, inventory and productivity. Therefore the objective of platforms is similar to both GT and lean design. Meyr and Lehnerd (1997) identify the key principles of product platforms:

- Identify families which share technology and are related to a market.

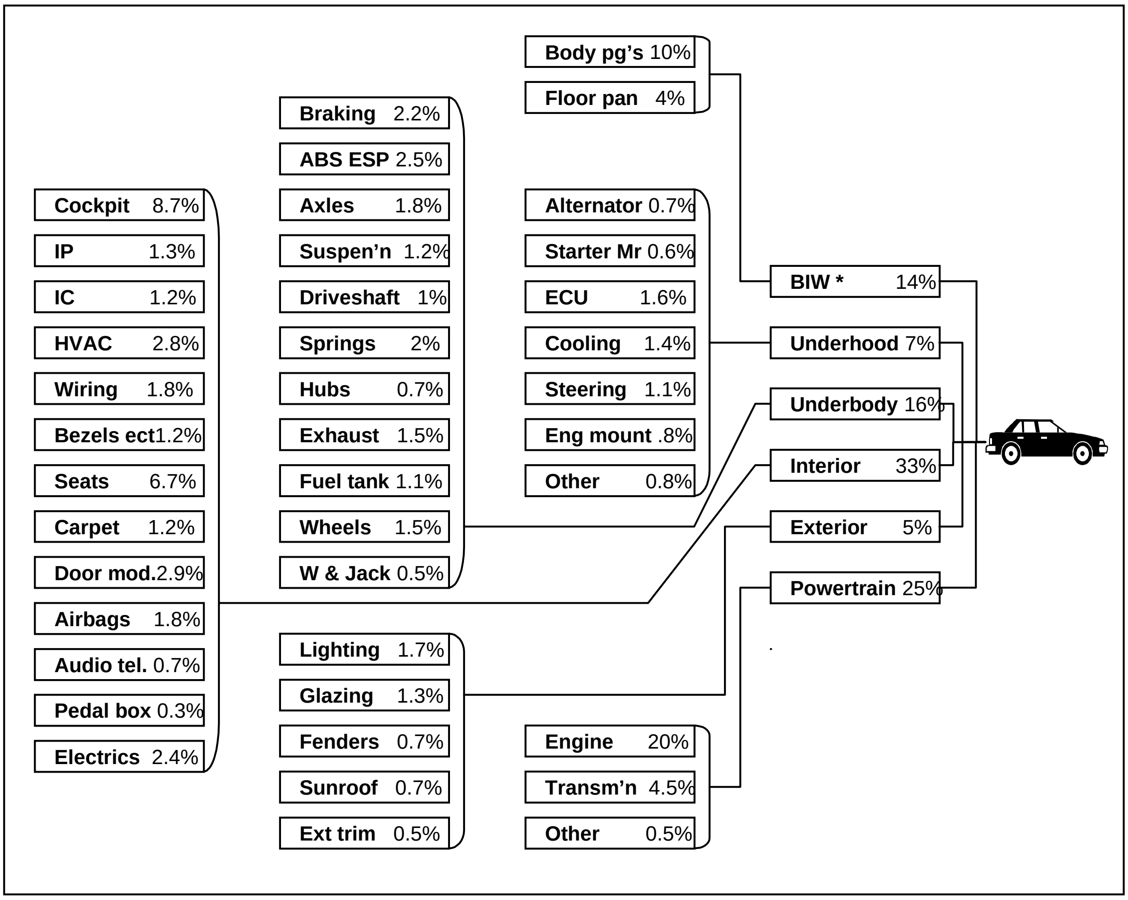
[1] This is called 'shelf technology' in some organisations.

- Embark on design that gives consideration to the customer as well as the machine.
- Design for global standards, logistics and component supply.
- Capitalise on latent demands that a product platform can create.

1.6 Methodology

The following chapters examine vehicle design in terms of the opportunities for minimising internal complexity whilst maximising external variety. It is useful here to identify where the greatest areas of value exist. Figure 3 illustrates a breakdown of component sub-assemblies for a typical C segment vehicle. It shows that the component assemblies of greatest value are engine: 20%, body & floorpan pressings: 14%, and the cockpit module: 8.7%.

Figure 3 Procured cost of components (C segment vehicle)



* Adjusted to include raw material, paint and % of stamping / pressing costs. Source: Adapted from Goldman Sachs

This report examines body construction, powertrain and modules in chapters 2, 3 and 4. The body represents around one seventh of the total value of a vehicle and has a fundamental impact on the entire nature of production. Chapter 2 includes data collected from a number of recent visits to European plants, where alternative construction methods have recently been introduced. This builds on the work already completed in the Spaceframes report.

Vehicle electronics, Chapter 5, describes the increasing dominance of telematics and mechatronics in current vehicle design. There are significant implications for both internal complexity and external variety with the introduction of multiplex and X-by-wire systems.

Vehicle Design

Designing a recyclable 3DayCar, Chapter 6, examines the issues and 3DC implications of vehicle disposal and recycling. It will soon become EU law for all VM's to comply with disassembly regulations. Chapter 7 examines the critical area of vehicle costs. Cost reduction and profit opportunity are examined with the use of a cost model, created for this report. It illustrates what the implications are for variable and fixed costs in terms of moving to future vehicle design and BTO production.

2 Body construction

Body construction is important because it affects the number of body variants in production. Also, modular bodies offer flexibility for changes to new products in terms of time and cost savings. Two approaches can be used to minimise the impact of complexity and variety on production: process based approaches such as flexible manufacturing equipment, or product based approaches using platforms, modular designs and component standardisation. Increasing attention is now being focused on product design, where it is in the *nature of the product architecture* that much of a manufacturing systems ability to manage variety resides.

2.1 Monocoque and 'decoupling'

Building the 3DC using conventional steel monocoque construction presents a major challenge due to bottlenecks such as the Paint shop, which requires significant body batching, re-sequencing and buffer stock. Paint is a major source of waste, quality defects and unreliability in the production system, which limits manufacturer's ability to predict the completion of individual vehicles and inhibits rapid BTO. [1]

A technique that may improve current production and is of particular relevance to 3DC is Decision Point Analysis (DPA) or 'decoupling'. It assists in determining the key point where the 'pull' ordering of the customer meets the 'push' scheduling of manufacturing. It focuses the factory operations in relation to postponing the identification of customer orders to specific vehicles until the latest possible stage of production. This approach suggests that the trigger point can be brought further upstream as efficiencies in operations are perfected, and raises the issue of how vehicles can be designed for late configuration in production (Holweg, 2000).

In conventional production, this could be translated into holding stocks of painted bodies before the vehicle assembly line. In effect, the painted body store would become the trigger point at which a specific customer order commences production. The less body variants at this point, the less stock is needed to ensure a match with a customer order.

However, moving from a push / batch manufacturing towards a pull / OTD system may require increasing stock levels of components in order to achieve the flexibility to build variable customer order demand and reduce or eliminate finished vehicle stock in the market place. This represents a significant change in mindset for OEM's who are used to the principles of Lean Thinking and the elimination of waste.

2.2 Alternative body construction

Despite the predominance of conventional, steel monocoque construction, interest by volume manufacturers in alternative methods of body construction such as spaceframes has increased significantly in Europe / US over the past decade.[2] Driven by the need for more model variants, fuel efficiency and profits, manufacturers are experimenting with new materials, construction and assembly methods.

Alternative methods of body construction have significant implications for 3DC. An independent structural body and exterior panel design can significantly reduce the impact of existing bottlenecks on production. For example, the construction of the Daimler Chrysler Smart car allows the virtual elimination of traditional paint shop activity by fitting coloured thermoplastic panels at final assembly. Only four body variants, two different frames in two colours, enter the assembly line with obvious

[1] Howard (2000) 'The 3DayCar Paint Shop Survey'.

[2] Howard (2000) 'Spaceframes: study of an emerging body construction technology'.

reliability impact. This offers the flexibility to produce many different specifications with any body variant. Significant improvements can be achieved in terms of one piece flow and leadtime reduction compared with conventional, large-batch manufacturing.

Figure 4 compares the results from a number of visits to volume manufacturers in Europe. The chart compares monocoque, spaceframe and steel body / plastic panel construction. Some significant findings emerge from the data: when compared with welded steel monocoque, the total number of structural body parts per vehicle (pressings, folded sheet, castings & extrusions) *increases* in alternative methods of body construction.

However, interviews with engineers revealed that a key constraint during the design development phase of the body was the cost of the tools required to press the vehicle's left & right side panels and floorpan. A solution to this was to design smaller pressings that could be joined together during

Figure 4 Body construction methods in Europe, 2000

Vehicle Manufacturer	**A**	**B**	**C**	**D**
Body construction	**Welded steel monocoque**	**Spaceframe**	**Spaceframe**	**Pressed steel / plastic panels**
Segment / class	B	B/C	B/C	A
Total capacity (pa)	250,000	60,000	75,000	200,000
Body tooling: (£)	63,000,000	60,000,000	Na	20,000,000 (+ mould tools)
Body weight : **Total vehicle:** (kg)	200 1000	232 1300	130 895	158 720
Body assembly automation (%)	85%	20%	85%	95%
Body assembly leadtime (hours)	7.5	12.5	7.5	2
Paint shop colours	14	10	8	2 (frame)
Large pressings **Small pressings** **Folded sheet** **Castings** **Extrusions** **Total:**	40 na - - - **90**	29 60 20 - - **109**	20 35 - 18 28 **101**	30 na na - - **106** (+10 plastic panels)
Method of fixing exterior panels to body	Robotic spot weld	Manual spot weld	MIG seam welding and steel rivets	Plastic clips

production, as is the case with models such as the Fiat Multipla and DC Smart. In theory, an increase in the number of parts represents an inhibitor to rapid BTO. However, if these parts can be shared with other model variants and across platforms, as currently proposed by the Fiat / GM partnership, this reduces complexity overall across the model range and represents a considerable saving to the manufacturer. In addition, produce change cost is reduced.

Neither the steel or aluminium spaceframe plants visited are capable of de-coupling production. Their exterior panels still provide some degree of structural rigidity for the vehicle and therefore have to be built in the conventional manner: Body assembly - BIW store - Paint shop - Painted body store - Final

Assembly. After the plant visits, the term *independent body and panels* (IBP) has been coined rather than using spaceframes in a generic sense, since any body construction which has independent painted panels meets the body construction requirements of 3DC.

The following conclusions are drawn:

- While IBP is used on smaller volume models it is beginning to be used on higher volume vehicles.
- Body Weight: IBP can be considerably lighter than monocoques. This is because the nature of construction of IBP allows different materials to be used. Attempts to reduce the weight of steel monocoque, such as ULSAB, have not been particularly successful because 'laminating' methods used are expensive and make recycling difficult.
- Body Assembly Automation: IBP is possible using either higher labour or automation during body assembly than for the monocoque, because there are 10 to 30% more body parts with IBP.

  Despite this, the number of painted body variants entering the vehicle assembly track is significantly reduced because there can be few colour differences at this stage. Therefore, customer order lead time can be significantly reduced with IBP.

A true spaceframe enables the de-coupling of paint and body assembly from production. This means that the modular[1] body construction provides a set of generic parts with which to build a saloon, hatch, estate or MPV. The only (partial) example of this today is the Land Rover Defender series, where by simply extending the chassis, it is possible to build different versions i.e: long / short wheel-base.

The Independent Body and Panel (IBP) approach de-couples paint from production. Exterior panels can be painted separately from the vehicle body, for example the GM Saturn EV-1. A variation of this is the use of thermoplastic panels, where the use of in-moulded colour means that the paint shop and surface quality / reliability issues are removed from the line, such as in the DC Smart plant, Hambach. The following includes potential 3DC enhancing technology, encountered during the plant visits:

- **Thermoplastic body panels.** GE Plastics has developed 'Xenoy': a tough, exterior grade panel material capable of accepting a polyurethane clear coat on its surface and incorporating an ultraviolet resistant colour pigment during the injection moulding process. Xenoy fulfils all automotive salt spray testing & crash/safety requirements.
- **Vacuum pressure aluminium die-casting.** Capable of producing highly accurate, large and load-bearing components, such as side-pillars as one complete part on the Audi A2, instead of 6 on the A8. Providing the components have a universal jointing system, they could be shared with different models of similar height.
- **Glazed roof panels.** It is now possible for a separate totally glazed roof panel to be fitted to the car in final assembly. In order to eliminate the traditional 'sunroof option' from BIW, a separate sunroof panel can also be fitted in final assembly.
- **Hydro-forming.** Used in volume production of steel and aluminium pressings since 1998, water is injected into the metal blank or extrusion during forming in order to prevent the walls of the component collapsing. This allows more complex shapes to be developed per part, eliminating sub-assembly work. Whilst hydro-forming requires volume for cost efficient production, with implications for capacity utilisation, some flexibility must be retained in the design of the part that allows it to be shared with other models.

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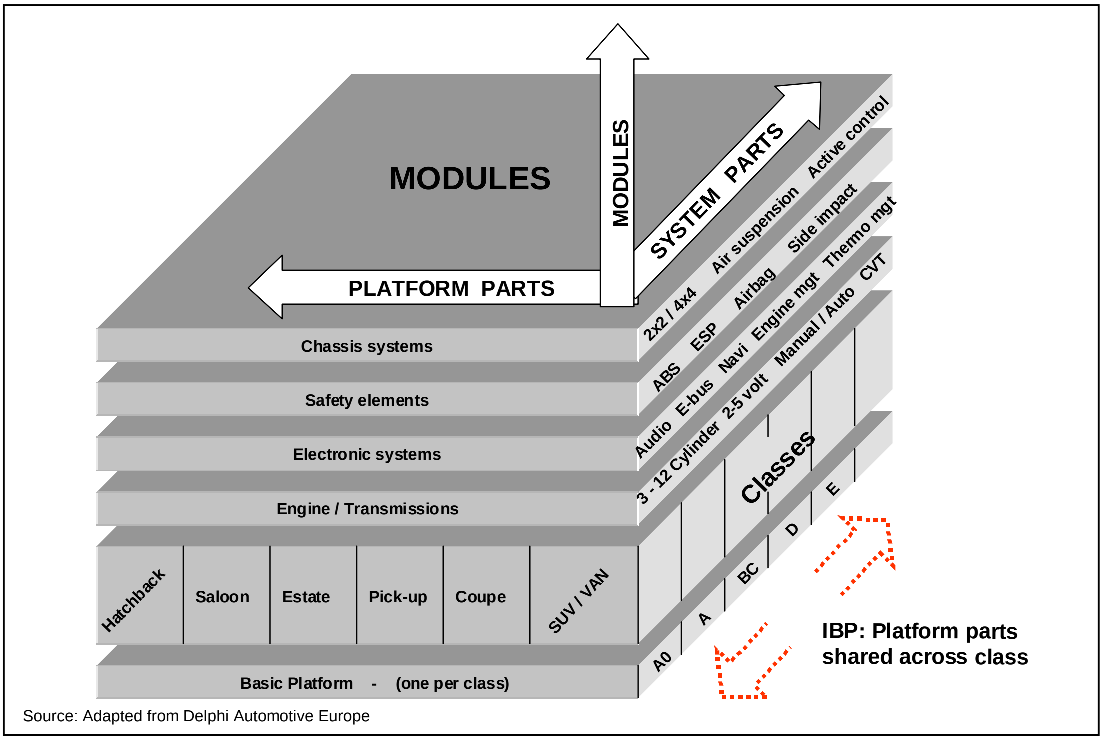
[1] Modular: '*..independent units that can be combined in different ways.*' (Oxford Dic.)

2.3 Platforms

The platform concept shown in Figure 5 is based on standardised components, offering a combination of high model variety with comparably low levels of complexity. Volkswagen makes the world's biggest selling platform and has achieved a high degree of parts commonality, 65% in the case of the Golf, A3, Seat and Skoda platform. The recent spate of alliances, mergers and acquisitions in the car industry and the emphasis on restructuring has identified the standardisation of platforms as the obvious way to extract synergies, such as the Ford/Jaguar/Volvo conglomerate. Some manufacturers are adopting totally modular production, passing full responsibility for the assembly of complex commodities onto suppliers (e g VW's 'Blue Macaw' truck plant, Brazil, and DC Smart Car).

Figure 5 The platform concept



Source: Adapted from Delphi Automotive Europe

The precise definition of a platform varies between manufacturers, but in all cases includes the floorpan pressing. In conventional welded steel monocoque construction the body costs 15 to 20% of the total vehicle, of which the floorpan pressing accounts for 40%. It is expensive because of its large surface area and the thicker metal used in construction. Maximising floorpan production volume is highly desirable, achieved by extending its use across as many models as possible and from one generation of vehicle to the next.

Despite more body components, an advantage of alternative construction technologies such as spaceframes and IBP is that the floorpan pressings are divided into smaller pieces, fabricated from flat sheet or pressings and supported by transverse beams constructed from folded steel or extrusions. This means that engineers are not restricted to using predetermined floorpan dimensions and have greater design freedom over new model variants.

Therefore, alternative methods of body construction can redefine the current limits of platform sharing. Common platform elements[2] that have no impact on the vehicle's outer skin can be retained,

[2] Bremner (1999) *FT Auto World*, Sept. Defined as comprising of: 'chassis, wheelhouses, front axles, wheels, steering column, front end members, gearshift mechanism, pedal cluster carrier, rear axles, bulkhead, brake systems, centre floor, fuel tanks, rear end, exhaust systems, seat frames and wiring & electronics.'

whilst an almost infinite variety of new model shapes will be possible from a basic kit of modular, structural components. This goes some way towards addressing the 3DC challenge: achieving mass customisation[3] whilst minimising complexity through an integrated approach to parts sharing.

Creating a modular platform as the basic unit of body construction would virtually eliminate the need for individual platforms by class / segment (see dotted arrow in fig 5, p14). The current relationship between platform, module and system parts is key to understanding where it may be possible to reduce vehicle complexity across model ranges and brands, a theme which is revisited through out this report.

2.4 Plant distribution

Spaceframes and IBP raise several issues over the distribution of production plants. Because of the cost of duplicating large press tools, conventional practice is either to press and assemble the vehicle at one central location, transport finished panels and body parts and assemble in a number of smaller plants close to key sales areas (i.e. KD production). The time and drain on resources required in shipping either finished vehicles or large quantities of bulky pressings across long distances is beginning to be questioned by the industry. The nature of alternative body construction with its greater number of smaller components suggests opportunities for sharing across models, where more body parts can be produced and configured locally. This matches the requirements of smaller, regional plants such as the ‘Micro factory retailing’ MFR concept (Wells & Nieuwenhuis, 2000). Two conflicting strategies emerge here: produce locally and be more responsive to demand, or produce globally and take advantage of the economies of scale.

2.5 Summary

- The platform concept is based on standardised components, offering a combination of high model variety with comparably low levels of complexity. Platforms benefit 3DC because they allow greater flexibility across models and brands, for example Ford, Jaguar and Volvo, increasing flexibility, product mix and capacity.
- While the retention of brand differentiation must be carefully considered in the development of platforms (and modules), using the latest developments on the strongest brand cars can assist in reducing the possible negative effects of standardisation.
- The total number of structural body parts per vehicle *increases* in alternative methods of body construction. This is contrary to 3DC’s requirements of minimum complexity. However, if these parts can be shared across model variants and platforms, the overall complexity can be reduced.
- A true spaceframe de-couples paint and body assembly from production. This means that the modular body construction provides a set of generic parts with which to build a saloon, hatch, estate or MPV. The only (partial) example of this today is the Land Rover ‘Defender’ series, where, by simply extending the chassis, it is possible to build different versions ie: long / short wheel-base.
- The ‘Independent Body and Panels’ (IBP) approach de-couples paint from vehicle assembly. Exterior panels can be painted separately from the vehicle body, for example the GM Saturn EV-1. One variation of this is the use of thermoplastic panels, where in-moulded colour means that the paint shop and surface quality / reliability issues are separated from the vehicle assembly line, such as at DC Smart, Hambach.

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[3] I.e: maximum variety from minimum product complexity. J. Pines (1993) also describes this as ‘..*delivering affordable goods with enough variety so that nearly everyone finds exactly what they want.*’

- Body construction technology which can potentially enhance 3DC vehicle design includes: thermoplastic body panels, vacuum pressure aluminium die-casting, glazed roof panels / painted roof modules and hydro-forming.
- Alternative methods of body construction can redefine the current limits of platform sharing. Common platform elements that have no impact on the vehicle’s outer skin can be retained, whilst an almost infinite variety of new model shapes are possible from a basic kit of modular, structural components. This goes some way towards mass customisation, through minimising complexity and adopting an integrated approach to parts sharing.

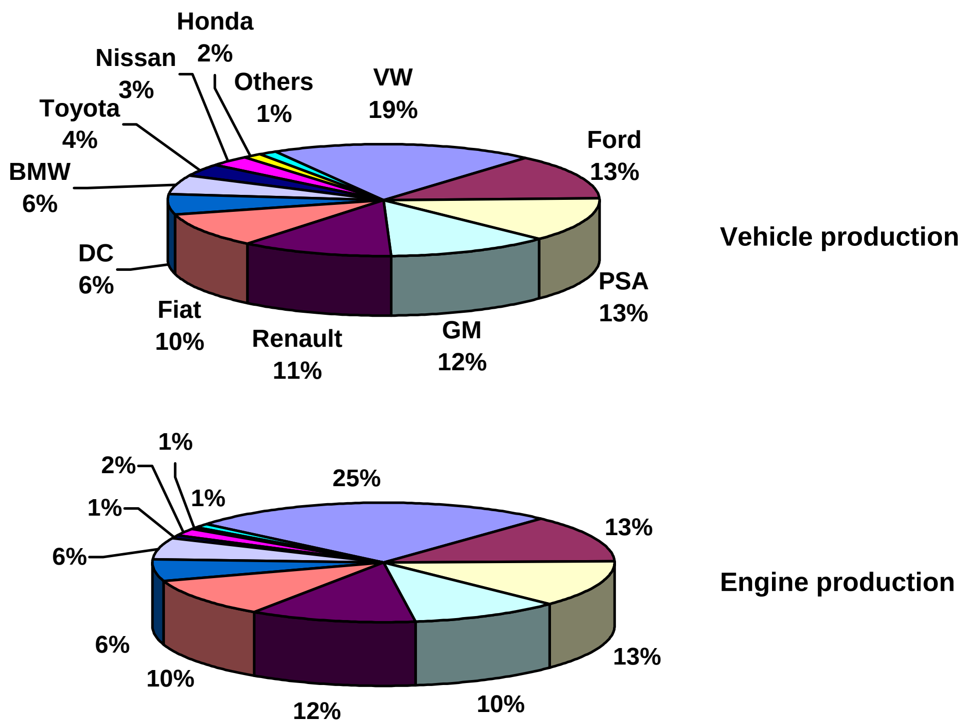
3 Powertrain

"I believe that there will be a time when various engines and power sources will exist simultaneously"
Hirojuki Watanabe MD, Toyota (2000)

3.1 Current Production

Over 56 million cars and light trucks were produced worldwide in 1999, 99% of which are driven by either petrol or diesel internal combustion engines. Europe comprises one third of this total, where the top five manufacturers by volume are VW, Ford, PSA, GM and Renault. Figure 6 below compares vehicle and engine production. It is common practice for VM's to develop trade agreements with other manufacturers or import their own engines from other areas of the world, such as Brazil. Given the high value of engines relative to the rest of the vehicle (see Figure 3, p12) and up to 3 weeks transportation at sea from other continents, engines are one of the major barriers to rapid BTO if they are not produced in Europe. Japanese manufacturers appear to have the greatest problem in this respect.

Figure 6 Vehicle and Engine Production in Europe, 1999



Source: 'Automotive News Europe Global Market Data' & 'World Automotive Manufacturing Engine Survey'

However, the current period of total market dominance by the internal combustion engine could be drawing to a close. Despite engine performance improving significantly over the past two decades, the environmental debate continues to focus on reducing car emissions and fuel efficiency. To meet future targets, Wells and Nieuwenhuis suggest the industry is faced with the adoption of at least one of a number of alternatives:

- Improvement of internal combustion (IC) engines, e g: direct injection
- Alternative engines: orbital 2-stroke

- Alternative fuels: alcohol, methanol, liquefied petroleum gas (LPG) & natural gas (CNG).
- Alternative powertrains: battery / electric vehicle (BEV / EV), hybrid and fuel cell.

3.2 The Impact of Alternatives

In powertrain, as in body construction, changes in vehicle design could have major implications on the organisational structure of the industry. This concerns the effect on existing technological and investment base in production and R&D with technological competitiveness moving away from the VM and towards the supplier. As suggested by Hirojuki Watanabe, a range of alternative powertrains could soon be available on the market. This could affect 3DC and the ability to adopt a rapid BTO strategy through an increase in technical complexity. The remainder of this chapter examines what impact the following changes might have on 3DC.

3.2.1 Improvement of Internal Combustion (IC) engines

While becoming lighter (with the shift from cast iron engine blocks and cylinder heads to aluminium alloy), existing IC engines are becoming marginally more complex. Whilst changes to engine design have seen the disappearance of parts such as the carburettor, this has been more than compensated for by the introduction of fuel injection, electrical controls, sensors, emission traps, catalytic converter and valve technology. The continued pressure on reducing emissions and reliance on fossil fuels means that before 2010, IC engines are likely to be just one of a number of economical means of powering transportation. Therefore, 3DC must consider the alternatives.

3.2.2 Alternative fuels

Alternative fuels are already used all over the world, including liquefied petroleum gas LPG (France, Italy, and Netherlands), Methanol (Brazil), and Natural gas (UK, Canada, Germany). These alternative fuels do not require a radical change to current engine production. However, emissions are only reduced not eliminated (and CO2 is not reduced at all). This can only, therefore, be considered an interim solution. Hydrogen, one of the strongest long term alternatives, can be used in adapted versions of existing engines, although it can also be used in fuel cells and therefore does not guarantee the future of current production systems.

3.2.3 Alternative engines

Innovations such as the Orbital 2-stroke, Mazda's Miller-cycle and the Stirling engine are similar enough to existing petrol and diesels engines not to require a significant change in production technology. However, their incremental improvement approach, using relatively conventional technology, promises little in the way of the short / medium term break-through required in order to satisfy increasingly stringent global emission and energy conservation requirements.

3.2.4 BEV / EV's

Electric vehicles (EV), powered solely by stored electrical energy, show great promise in terms of environmental credentials, but still lack the technological breakthrough required in battery technology to develop beyond the short-range 'urban rechargeable' models currently for hire in Japanese and some European cities today. The 'energy density' of petrol and diesel engines has allowed VM's in the past to design cars without weight minimisation as a priority (Wells and Nieuwenhuis (1997). Moving to BEV / EV's has a number of design implications, primarily that electric traction requires a different powertrain and lighter body construction compared to ICV's. The General Motors EV-1, currently available for lease across the US, suffers from the ongoing problem of the lightweight body construction merely compensating for the considerable weight of the battery pack. In the event of widespread Industry adoption of EV's, this would render much of existing engine production technology redundant, shifting technological knowledge from VM's to suppliers such as Bosch and Valeo.

3.2.5 Hybrid

The first full production models of a hybrid vehicle were launched in 1999: the Honda Insight and Toyota Prius. The key feature of the hybrid electric vehicle (HEV) is that it has two different power systems, typically an IC engine and an electric traction motor. Whilst able to select the means of propulsion most suited to current driving conditions: IC for acceleration, electric for cruising. Its dual power source also means it can store power from regenerative braking and engine idling. The advantages of this over a BEV are increased range and a 'smaller' battery pack, although still the equivalent to two large suitcases. However, the increased complexity of having two power trains per vehicle, has some considerable implications on component delivery for 3DC. The industry finds hybrids attractive because they follow the EV route without abandoning investment in IC engines. GM has announced that it will introduce a hybrid power train for the mass market by 2005.[2]

3.2.6 Direct Injection

An important powertrain development is the highly efficient direct injection (DI) engine, where the fuel is injected directly into each cylinder. Already, conventional DI engines get better mileage when combustion is triggered by highly compressing the air fuel mixture so that it self ignites, instead of using spark plugs. The DI engine can work in concert with a hybrid electric motor, because the engine can be smaller and turned off automatically when not needed, thus increasing fuel consumption and reducing emissions. However, hybrids are likely to continue both as a niche product and an interim solution, until the full development of fuel cells. The largest change during this decade will be the uptake of DI & diesel.

3.2.7 Fuel Cells

The fuel cell powered vehicle uses a simple chemical reaction to generate electricity, which drives an electric motor. Methane or hydrogen (extracted from methanol) is carried on board and is combined with oxygen during the reaction, which produces water. Excess energy is stored in a small battery pack. As a variation of the BEV/EV approach, which uses a similar form of lightweight body construction, this represent a radical departure from current production techniques. However, in terms of 3DC's requirements, it is less complex in terms of the number of components than the dual powertrain of the hybrid. Ford will launch its first production model fuel cell vehicle, the Th!nk, in 2002. It is claimed to overcome the infrastructure problems of supplying hydrogen, by using methanol as its fuel source. However, whilst methanol is a liquid under normal conditions and thus refuelling is identical to filling up with gasoline, this solution requires a methanol tank, a reformer, a delivery system to the fuel cell and then a delivery system to the motor. It is therefore very complex.

3.2.8 Direct drive

This is a little explored route based on the principle that a motor for each wheel is more efficient. Direct power is supplied to electric motors in the wheels, with no drive shafts or connecting rods. However, it does add complexity in terms of the number of motors.

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[2] Financial Times (2000) 3 Aug, '*GM hits back at rival over fuel efficiency*'

3.3 Summary: 'Powertrain 2010'

Wells and Nieuwenhuis (1997) predict that hybrid vehicles are the most likely short to medium term solution to 21st century personal transportation. The dual powertrain however, represents a significant challenge to 3DC. Over 10 to 20 years, it is suggested that BEV's and Fuel Cells will grow in popularity. Whilst focusing on one source of power, these will require different body, transmission, gearing and suspension requirements.

The importance of identifying and developing zero emission, energy efficient transportation, is creating a new wave of public and private sector collaboration such as Foresight (UK) and the Partnership for a New Generation of Vehicles (PNGV) in the US. In 1998, PNGV identified HEV's, DI engines, fuel cells and lightweight materials as the four key technology areas of the future. Other independent initiatives such as the Hypercar (the vision of Mr Amory Lovins, CEO of the Rocky Mountain Institute & Mr Thomas Crumm, CEO of Hypercar) and EUCAR reinforce the auto industry's growing recognition of the need to develop ecologically friendly transportation.

This means that the picture of production in 2010 will show a greater proportion of internal combustion (IC) engines using direct injection (DI) diesel engines. Whilst the competencies related to traditional powertrain development will remain with manufacturers, there will be greater collaboration with suppliers. Further enhancements in battery and fuel cell technology will occur in the mid-to-long term. Industry forecasts predict that fuel cells will form a significant proportion of the market by 2025. However, these developments are unlikely to have a significant impact on 3DC over the next 10 years.

4 Modules

> *" Module: a complex assembly which can be developed, manufactured and assembled independently. It must be interchangeable and capable of alternative installation."* *B Wilhelm, VW.*

This chapter defines modules, modularization and modularity. It examines the benefits of modules to 3DC, such as reducing complexity, contributing to production flexibility, and reducing assembly leadtime. It includes the impact of modularisation on suppliers and component standardisation.

4.1 Origins and definition

Modularity is a concept that is applied to manage complex systems, by breaking them down into parameters and tasks that are *interdependent within and independent across* modules (Baldwin and Clark 1997). Within the MIT International Motor Vehicle Programme 'Modularization and Outsourcing' project, Sako and Murray (1999) identify three types of modularity:

- **Modularity in Design** (MID): Designers of complex products use the concept of a product architecture, where the function of a product is allocated to physical components. Modular architecture involves mapping functional elements in the structure to the physical components of the product, specifying de-coupled interfaces between components. Design modularisation was first used in computer hardware by IBM in the 1960's.

- **Modularity in Use** (MIU): Customer based decomposition of a product into 'options' such as sunroof & wheel trim.

- **Modularity in Production** (MIP): The capability to pre-combine a large number of components into modules which are assembled offline, brought onto the main assembly area and incorporated into the vehicle through a simple series of tasks. This reduces in-line complexity, shifts complexity off the line and shortens the main line itself.

In the automobile industry the principle of modularisation has existed for a long time, as all VM's have produced engines and transmissions as discrete units. There is still debate today over the difference between a sub-assembly and module. During the past few decades however, a modular assembly approach has been adopted by many VM's, in order to remove complex and ergonomically difficult tasks from the assembly line. In 1980, the Fiat Tipo was the first model that simplified assembly and maximised opportunities for component sharing across other marques. This success was followed by other manufacturers: in 1985 the first cockpit module appeared on the Opel Omega.

The development of modules by volume manufacturers is driven by the desire to improve a number of factors such as cost and asset reduction, ergonomics, and technological competitiveness. Almost all Western module development is carried out externally by 1st tier suppliers with collaboration with VM engineers, a process described as 'outsourcing'. However, some Japanese manufacturers, such as Toyota and Honda, question the reliance on suppliers for quality-critical module technology and whether such a policy is sustainable long term, preferring instead to retain development in-house.

A typical breakdown of a conventional steel monocoque vehicle reveals the following modules: body, powertrain, front end, rear end, electrics, cockpit, seats, doors, roof, bonnet and decklid. An important distinction in vehicle design is defining the boundaries between modules and systems. Modules may be defined as '*physical sub-assemblies'* such as a seat. Systems can be defined as '*a collection of components not necessarily deliverable in one lump*' such as braking (Sako & Murray 1999).

A complex, interdependent / dependent relationship exists between the platform, modules and systems. During the design phase, systems tend to take priority. In the event of a system entering across the boundary of a module, such as wiring in a door, it is the responsibility of the module supplier to integrate the system supplier's component.

4.2 The benefits of modules to 3DC

A significant benefit to 3DC from modularisation comes from the concept of 'sharing', either internally within the vehicle, or externally across individual models and brands. Internally means enhancing the integral architecture within a module by functional sharing of single components and by 'geometric nesting': the efficient use of space and material. Externally means components and interfaces are standardised across models so that production cost may be lowered. Whilst a potential disadvantage of component sharing and standardisation is the danger of losing the distinctive 'look and feel' of individual models, this has to be balanced against the advantage of cost reduction and assembly flexibility.

Modularisation may enable suppliers to cope with a BTO environment. Current production is based on a forecast which is planned months in advance. This approach is designed to smooth output at the assembly plant and produce a continuous stream of vehicles. The cost associated with holding finished stock at plant, distribution centres and dealers, combined with the incentives required to encourage customers to accept an alternative specification to the one they desire or to purchase old vehicles, implies huge costs for the supply chain, whether VM or dealer. Moving towards a rapid BTO system will mean supplier scheduling having to alter considerably. Day-to-day fluctuations in customer demand and seasonal trends may no longer be smoothed. Parts supply also may move away from '*components dedicated to specific customers (i.e. VMs)'* and towards '*standardised components…switching supply between VM's according to demand'* (Warburton & Sako 1999).[1]

Figure 7 The benefits of modularity

Modularity in design	• Reduction in complexity resulting from reduction in parts / part numbers. • Shorter development leadtimes through parallel development of modules • Rapid adoption of new technology by upgrading modules separately
Modularity in use	• High product variety by offering customers the choice to 'mix and match' options to taste
Modularity in production	• Leaner production lines, due to reduced no. of operations • Flexible manufacturing by taking complex / ergonomically difficult tasks off the assembly line • Postponement of final assembly to realise high product variety without increasing production costs

Source: Adapted from Sako & Murray (1999)

Minimising internal vehicle complexity enables a BTO strategy by reducing inventories, part count and assembly lead time. However, the current emphasis on *integration* of modules within specific models, conflicts with the generally accepted notion that the automotive industry should increase parts sharing and *standardisation*.

[1] Warburton, M. & Sako, M. (1999) MIT / IMVP Modularization and Outsourcing project, Preliminary Report.

Optimistic predictions have been made regarding future 'web-enabled' vehicle specification, offering infinite customer choice using the 'mix and match' concept of base modules: body, chassis, engine and transmission with interchangeable seat, interior and cockpit modules. The limitation of this vision lies in the inherent conflict between the current high degree of module integration specific to a particular vehicle 'model' (eg Focus, Vectra, Punto) versus the level of standardisation required in the future to allow more modules to be interchangeable across models, even an entire brand. Due to the importance of aesthetics, the interface between external modules (for example the rear end module or 'bumper') and the vehicle's body panels is specifically designed to fit only one or possibly two models in the range.

Hidden modules in underbody environments, such as powertrain, can generally be adapted more easily for different models. It is interesting to note that the majority of leading cockpit integrators in Europe originate from plastic injection moulding backgrounds, indicating that exterior packaging plays as important a role during the design of modules as the electro-mechanical hardware contained within it.

Figure 8 summarises the state of module complexity and the potential for standardisation in current vehicle design. It highlights the significance of model-specific, *differentiated* parts such as exterior body pressings and interior plastic and trim (unlikely to be standardised) as opposed to *homogenous* electrical and mechanical parts such as HVAC and Engines (standardised). Given the trend of shortening vehicle lifecycle and increasing model variety, manufacturers are increasingly extending the life of some components and assemblies over a number of model lifecycles.

Figure 8 Module complexity and standardisation

Module	*Major components / sub-assy's*	*Comments*
Cockpit module	HVAC, Wiring / electrical Instrument panel (IP), I. Cluster, Steering, Airbag/s, Cross car beam, Airvents, Glovebox	Very complex module. VM's will always insist on different IP's, but some potential for sharing internal parts.
Door module	Glass, Glasshouse, Beltline Latch, Lock, Handle	Many parts very similar across models, although retaining the specific curve of the glass / glasshouse could be difficult.
Seats	-	Simple. Outsourced industry-wide.
Headliner	-	Model specific
Front end / rear end	Light cluster, Electrical, Bumper / trim, Sub-frame	Highly differentiated by model due to exact fit required to body.
Powertrain	Engine, Transmission, Suspension, Braking, Exhaust Fueltank	Complex, but many opportunities for sharing across model / brand / industry.
Wiring harness	-	On average, 100 wire harnesses offered per model. This will reduce with introduction of Multiplexing.
Body / chassis	Floorpan, L & R side pressings,	Welded steel monocoque means only floorpan can be shared. The future: modular bodies / IBP?

Significant reductions in production leadtime can be achieved by VM's forming partnerships with 1st tier suppliers. However, this means that much of the responsibility for delivery and stocking is passed back up the supply chain. The DC Smart car was designed so that 90% of value is added by suppliers and delivered to the assembly plant in modules. In addition, some options are late configured at customer centres. Lead time at the plant is currently c7.5 hours, less than half of conventional production.

However, it is also important to consider that a point may exist in vehicle design where it is no longer possible to simplify a component further, or to gain benefit by devolving design responsibility to suppliers. Some industry observers consider that outsourcing design and development of modular assembly's carries with it inherent risks, related to the loss of architectural knowledge and ultimately a loss of power and control over the final product[1]. A trade-off exists where the decision to outsource modules must ultimately be determined by balancing quality, development, delivery and productivity costs against loss of brand differential and power.

4.3 Module innovation

Recent innovations in module design in the US indicate a number of benefits to 3DC:

- **Painted door module**
  Johnson Controls and Oxford Automotive are designing a new way to make vehicle doors, which will change the way VM's assemble cars. They plan to combine as a complete unit: the interior trim, motors, glass/glasshouse, latches and the exterior painted panel. This will be produced outside the VM plant, indicating that smaller paint shops at 1st tier supplier level are capable of reproducing the full range of body colours in highly visible, quality critical surfaces of the vehicle. This is in addition to the wing mirror covers and bumpers which suppliers already paint at present. Managing the removal of doors from the BIW for painting and their replacement during final assembly, has traditionally been a source of delay in production.[1] Outsourcing doors and treating the entire assembly as a module is a significant step in removing complexity from vehicle manufacturer production.

- **'Mix and match' Interiors**
  Lear, one of the world's largest suppliers of auto interiors, has designed a system to allow customers to personalise interiors. Based on mass customisation, the concept relies on a standardised, common structure that can support any combination of modular parts, including seats, steering wheels, instrument panels, door trim and overhead panels. The key to the personalised interior is the common architecture that interfaces with the choice of options. Common electrical interfaces would allow customers to 'plug and play': choosing their own combination of audio, route-finding and communication equipment according to individual taste. This would provide higher value for car buyers for which suppliers and manufacturers could build to order. For the 3DayCar, these interiors would have to be customised and delivered to the assembly line within the two-day notification of precise customer order requirement.

- **Roof module**
  Arvin Meritor, supplier of the composite roof for DC Smart, anticipates sales of its new roof module will reach 500 million dollars within five years. The benefits come from fitting the roof on the vehicle assembly line at a later stage. This allows workers to fit seats & IP's more easily. In addition, by eliminating steel and using lightweight aluminium or plastic, the vehicle's centre of gravity is lowered. The roof module is also a key benefit to 3DayCar. It can be supplied with a

[1] Batchelor, Bates and Croom (2000) 'Retaining architectural knowledge within automotive design chains'

[1] 'Segmentation and sequencing overview' Unpublished VM internal report

sunroof and fitted in final assembly, a similar concept to the glazed roof panel in Chapter 2. This reduces the number of BIW options at the start of production.

4.4 Summary

- Modules benefit 3DC by reducing vehicle complexity in design and by removing complex assembly procedures from production. Minimising internal vehicle complexity enables a BTO strategy in terms of reducing inventories, part count and assembly leadtime. However, this means that much of the responsibility for delivery and stocking is passed back up the supply chain.
- The benefit of modularisation is derived from the concept of ‘sharing’ component assemblies, either internally within the vehicle or externally across individual models and brands. However, a disadvantage of sharing and standardisation is the danger of losing the distinctive ‘look and feel’ of individual models.
- Whilst the current emphasis in vehicle design is on module *integration,* which suggests that they may become more model specific, this conflicts with the generally accepted notion that industry should increase parts sharing and *standardisation.*
- Current plans to introduce painted door modules, interior modules and roof modules will significantly reduce production leadtime. However, this can only be achieved by VM’s forming close partnerships with 1st tier suppliers. The roof module is particularly relevant to 3DC as it eliminates the sunroof option at the BIW stage, and postpones it until final assembly.

5 Vehicle Electronics

"The basic functionality of 90 per cent of all future innovations in cars will be determined by electronics." Dr W. Schleuter, Audi.

5.1 Telematics and Mechatronics

The 'information intensive' vehicle will soon become a familiar feature on the roads and highways around the world. In the US, the equivalent to 10% of the working populations' time is spent in their cars.[1] Services range from phone, fax, e-mail, voicemail, news, weather, travel bulletins and GPS[2] navigation. New features may include video e-mail, collision avoidance, security (automatic vehicle tracking & rescue services) and voice recognition systems. Intelligent Transportation Systems (ITS) are already operating in some countries such as Japan, used for remote toll collection and congestion avoidance. 'Telematics' the term given to the transmission of computerised information to and from cars, will both alter the future driving experience and require a new vehicle electrical architecture.

The development of functional electronics is also changing the way cars operate and function on the road. 'Mechatronics' is the combination of mechanical and electronic devices that merge to form a subsystem in a car. The application of electronics dominates engine and transmission management systems, climate control, ABS, safety & stability systems and vehicle lighting. The basic functionality of 90 per cent of all future innovations in cars will be determined by electronics. The rapid progress in automotive electronics design is a spin off from the computer revolution in commercial and domestic appliances. As the power and capability of electrical processors has accelerated, new manufacturing techniques have brought component prices down and enabled dramatic downsizing. Computer processors today are between 5000 and 25,000 times smaller than they were 30 years ago.[3]

If these new electrical products and services are left to develop independently from core design development activity, vehicle complexity will reach unacceptable levels and the chance for sharing and integration will be lost. What are the key technological opportunities currently emerging in vehicle electronics that will enable rapid build to order?

5.2 Multiplex

Multiplex communication technology, or MUX, consists of a single wire or optical fibre which dramatically reduces the size and complexity of the vehicle's wiring harness. A typical family saloon today requires over 100 variations of harness, consisting of miles of copper. This maze of wires and potentially troublesome electrical contacts is being replaced by MUX that uses a single power ring main, where switching is performed remotely at each unit by digitally coded signals, sent along a small data wire, or bus. These high-speed data systems, known as Controller Area Networks (CAN) have been developed with the capacity to transmit data up to one million bits per second. Each electrical component in the vehicle contains a smart chip that recognises and responds to its own signal. Demand for silicon chips in the automotive industry has doubled since 1990, and will double again by 2005.

MUX represents a new electronic architecture that will undoubtedly grow. Whilst currently only used in executive models such as the Audi A8, TT and Volvo S80, it is expected to spread across all model segments in the industry as the cost of components such as semi-conductors reduces. Its key benefit is that new systems can be added without any increase in the wiring. This provides manufacturers with total flexibility in specification and the capability of any combination of options at production,

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[1] Source: Goldman Sachs

[2] Global Positioning System (GPS)

[3] G. Howard (1999) *The Audi magazine* 'Processing Power' p56, Autumn / Winter Edition

dealership or any stage of the vehicle lifecycle. This has given rise to the expression ‘plug and play’: a concept briefly described in Chapter 4 and of great significance to 3DC. MUX is therefore a generic, modular system, capable of reducing the number of parts per model and offers a new means of delivering products and services to the customer.

The emphasis on electronics as a means of differentiating design is driving a number of imminent changes in the industry: a universal 42 volt vehicle power supply, standardisation of electric components (battery, motors, fuses and relays) and recognition of the major European protocols (CAN, LIN and TTx). The harmonisation of electrical architecture and protocols is a key factor in providing a stable platform, capable of sustaining and delivering a seamless information package to the consumer. Standardising electrical interfaces is important where vehicle networks currently comprise between 15 and 50 electrical control units (ECU). This is expected to peak at over 100 during the next 5 years.

5.3 Engine Management Systems

Powertrain and engine management systems are designed to optimise and control vehicle performance. It is currently possible to purchase an off-the-shelf engine control module (ECM) that can boost engine performance by up to 20%, with no other modifications necessary. The benefit to 3DC lies in the concept of one common powertrain unit where a choice of performance levels can be selected simply by modifying the electronic software either in production or remotely by the customer calling a service centre. This could help eliminate some of the complexity associated with the variety of engine sizes currently offered with all models.

5.4 X-by-wire

X-by-wire means control via electrical signals, rather than by direct pressure from one's hand or foot transmitted via gearing or hydraulics during steering or braking. For example, brake-by-wire is based on the brake pedal generating an electrical signal to act on electromechanical actuators placed in the brake of each wheel. Whilst ‘by-wire’ is an emerging technology, its successful use in Formula 1 racing suggests that it will eventually supersede traditional methods. Benefit to 3DC centres on less mechanical parts being required, such as hydraulic cylinders, brake lines and fluid, and consequent simplification of vehicle design. The first systems will be hybrids, keeping a hydraulic back-up system. Complete electromechanical systems are not expected for between 8 to 10 years.[1]

5.5 Vehicle Diagnostics

Vehicle diagnostics systems are currently used in monitoring engine performance, although ancillary diagnostics for safety systems are also being introduced on premium models. In theory, if microprocessors are attached to every vehicle system, this represents an increase in complexity. However, modern electronic hardware tends to be very similar in construction, where it is the *programming or software inside* that determines specific functional characteristics. Although the proportion of vehicles controlled by electronics is steadily increasing, this is not considered to be a significant inhibitor to 3DC.

The increase in the use of electronics will mean that microprocessors and ECU’s in modules may have to be tested twice, initially by suppliers and again as part of a complete vehicle check during production. With the trend continuing towards outsourcing and with responsibility for module warranty shifting to suppliers, ‘remote diagnostic technology’ may soon become an essential feature of vehicle electronic architecture. This idea could be extended to the remote control of vehicle and module features whilst in use. However, the required legislation may take many years to be established.

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[1] Wright, C. (2000) *Automotive News Europe* ‘SKF / Brembo join the race for brake by wire’ June 5.

5.6 'Plug and play'

The introduction of MUX means that the electrical architecture is now available for the concept of 'plug and play': tailor-made electrical options fitted according to customer specification. The additional vehicle complexity this creates could be removed from production through late configuration of audio, communication, travel, GPS, smart cruise and other features at customer centres. However, this raises the issue of vehicle warranty[1] and the additional costs of installation at a dealer, which are higher than on the assembly line.

Taking the concept a step further, all features could be automatically programmed into every vehicle as it passed through production. On delivery to the customer, they would pay only for the features they wished to be *switched on*. In theory, this system could apply to all electronic options, including engine performance, suspension settings and possibly even climate control. Whilst this offers a radical solution to the issue of vehicle complexity for 3DC, will there ever be a justification for fitting a mechanical device which isn't switched on? In practical terms, will customers be prepared to pay the current large price differentials, for instance between engine sizes or for air-conditioning, when they are *switch-on* options. The answer is almost certainly no, and therefore such introduction will lead to a reduction in profit potential given current pricing mechanisms.

The above scenario suggests that it is the process as well as product complexity that must be simplified. Perhaps it is not complexity that is the issue here, but *multiplicity:* where every vehicle is high specification, but with only certain options and features activated at the last possible moment before delivery. Electronics are possibly the exception to the rule that eliminating complexity enables BTO, providing that it can be created before the '3 day clock' starts. By incorporating very complex components and systems into the 3DC in this way, complexity becomes a very important means of overcoming the vehicle variety barrier. [2]

5.7 Summary

- The increase in development of telematics and mechatronics suggests that cars will become more complex. It is expected that 90% of the basic functionality of future innovations in cars will be determined by electronics. However, by incorporating complex electrical components and systems before the '3 day clock' commences, complexity can become a very important means of overcoming the vehicle variety barrier.
- Multiplex (MUX) represents a key enabler to 3DC where, a single optical fibre with Controller Area Network technology (CAN), eliminates hundreds of variations of traditional wiring harnesses. MUX potentially allows electronic options to be added during production, at the dealership or at any stage during the vehicle lifecycle.
- X-by-wire technology for braking and steering can potentially reduce internal complexity through electronic control. Its benefit to 3DC means that less mechanical parts are required, such as hydraulic cylinders, brake lines and fluid. However, the first systems will retain a hydraulic back-up. Complete electromechanical systems are not expected for between 8 to 10 years.
- Whilst microprocessor and electronic control units (ECU) content per vehicle is expected to increase, this is not expected to significantly increase complexity, as it is the programming of the software inside that determines specific functional characteristics. A current example of this Engine Management Systems (ECM) which electronically controls engine performance.

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[1] Japan has the greatest consumer demand for after-market electronics, but co's such as Toyota place considerable emphasis on Original Equipment (OE) in order to maintain market share and the vehicle's warranty.

[2] Concept developed in discussion with Dr M Sporton. Multiplicity: *'..a large number or variety'* (Oxford dic.)

- Whilst the concept of ‘plug and play’ for remote electrical options is now technically feasible with the introduction of MUX and CAN, this poses a number of issues over who bears the costs of warranty and installation.
- There is likely to be a problem of pricing for profit. Current large pricing differentials between engine sizes and other options may not be feasible in the future, if the customer perceives they need only to be *switched on.*

6.0 Designing a recyclable 3DayCar

"Waste is not something which comes after the fact…Picking up and reclaiming the scrap left over after production is a public service, but planning so that there will be no scrap is a higher public service".
Henry Ford[1]

The aim of this chapter is to review the background of recycling development, how design for recycling is enabled and whether conflicts arise between design for recycling (DFR) and design for quick, simple assembly and manufacturing. This is a primary goal of the 3DayCar.

6.1 Why is Design for recycling required?

Waste legislation is making disposal in landfill more and more expensive. In the foreseeable future disposal in landfill will not be possible due to lack of space. This is already occurring in some smaller European countries. Legislation has thus been driven to consider ensuring that products are significantly more recyclable. Recently this has culminated in the End of Life Vehicle Directive requiring vehicle manufacturers to be partly liable for the costs of free takeback of ELVs and the recycling of 85% of each vehicle by 2006 (95% from 2012). All vehicles will be subject to the directive in 2006 (all 'new' vehicles from 2002). Vehicle Type Approval will start to include recyclability standards (i.e. % recyclable) once a common format for this has been agreed, targeted date for 2005.

Article 4 of the directive states that Member states must motivate *"vehicle producers to encourage the design of new vehicles to facilitate dismantling , reuse and recovery*" and also "*to integrate an increasing quantity of recycled material in vehicles and other products in order to develop the markets for recycled materials*".

In particular, the end of life vehicle directive is requiring manufacturers not to use specific types of hazardous material in their cars such as hexavalent chromium and mercury by 2003. All plastics must be labelled by type to enable identification for recycling purposes, although Volvo has stated that it is impossible to label parts less than 50g in weight. However, the Ecris (1998) project found that recycling is not economically feasible in some cases. Life cycle studies show that a mixture of material recycling and energy recovery is more benign when recovery levels are required to be high (85-95%). Energy recovery of used material such as shredder waste will not count towards the recovery percentages. This demonstrates some of the weaknesses of the legislation.

Vehicle manufacturers are pre-empting this legislation and have been doing so for a number of years. In most European countries VMs have signed agreements to achieve better vehicle recyclability of 85% by 2002 on all scrapped vehicles. In the UK this has been through the ACORD agreement, co-ordinated through the SMMT, which has been signed by the majority of UK manufacturers as well as material suppliers. This agreement sets targets for recycling and re-using vehicles and parts.

6.2 What are the main factors?

Keoleian and Menerey (1993) were among the first to detail the requirements for 'designing in' allowances for disassembly and recycling. These are shown in Figure 9. They found that 'designing out' environmental problems is the most cost effective way of complying with recycling legislation. But design must also incorporate a great number of other factors including function, security, ergonomic requirements, production and assembly simplicity, quality fulfilment and cost. Many of these factors can contradict recycling requirements and vice versa. Appendix B shows current VM activity in this area.

[1] In fact, Ford used wood recycled from packaging crates to make floors on the Model-T.

As explained in section 1.5, design changes need to be resolved early on in the process, if late changes incurring high cost are to be avoided. As part of the simultaneous engineering of new products, recycling factors should be included in this process alongside DFM and DFS (Design For Serviceability).

Figure 9 Key factors in design for recycling (DFR).

Design factors	**Description**
Coding of plastics parts	Parts must show the type of plastic
Reduced component mounting points	Makes dismantling easier
Standard mounting points	Same tools can be used for dismantling
Quick release fasteners	Easy to take off parts
Better access to mounting points	Quicker to dismantle
Limit number of materials for the same function	Reduces different types of material for waste streams
Compatible materials per modular assembly	Can recycle parts together (no need to dismantle)
Use materials which can currently be recycled with existing infrastructure	Economic to recycle the material
Limit or eliminate materials which cannot be recycled	Enables reaching recycling target
Drain points lowest on fluid reservoirs	Enables depollution of the vehicle
Do not glue in removable inserts (e.g. filter in air filter)	Easy to dismantle plus no adhesive contamination of material
Reduce adhesive use generally	Reduce adhesive contamination
Eliminate black list, reduce grey list materials	Materials which are toxic or cannot be recycled
Use recycled material in new vehicles	Encourages a market for the material
Cost benefit recyclability and use of recycled material	Does cost of recyclability balance with gain in easier recycling/dismantling/reuse of material

Source: Adapted from Keoleian & Menerey (1993) and various VM Environmental Reports.

The results of a survey of material engineers at a number of vehicle manufacturers showed that the factors tabulated above in Figure 9 cover the majority of the issues to be considered in designing for recycling. Although many factors could be viewed as micro-issues, such as standard mounting points and quick release fasteners, they have a huge impact on the economics of vehicle dismantling. Conversely, some of the other factors such as limiting the number of materials and using recycled materials have significant implications for basic material choice, structure of the supply chain and surface finish and perception of quality by the customer.

The significance of these factors for 3DayCar must be in terms of BTO requirements as shown in section 1.2. These requirements have a minimal effect on technical complexity, stock and production of components in a short leadtime, as well as on the assumption that 3DayCar facilitates fast assembly whilst maintaining recyclability within cost constraints. The next section details where the main impacts of the environment on the 3Day Car are likely to be.

6.3 Impacts on the ability to make the 3DayCar

The degree of impact on 3DayCar due to designing recyclability into new vehicles is shown in the table below:

Figure 10 The impact of DFR on new vehicle production

Impact	Factor	Comment
No Impact	*Coding of parts*	Already carried out and has negligible impact if within model cycle. A tooling cost implication since usually a different tool per material type.
	Quick release fasteners	Conflicts with function and durability in some cases
	Better access to mounting points	Already done for increasing design for serviceability - also carry out virtual dismantling to calculate effect
Positive impact	*Reduce mounting points*	Easier, quicker assembly - a plus for general design
	Standard mounting types	Smaller parts bin and fewer tools on the line to use
	Limit material used for the same function	Fasteners included in mouldings - simplifies assembly & reduces part numbers
Negative impact	*Limit number of materials used for same function*	Can reduce specification variety that can be offered – particular problem for niche/low volume/luxury segment
		Modules with ‘bonded exterior skins’ are in conflict with single sourced material and recycling.
	Use material which can be recycled	If create own market for material, it can lead to volatile supply (although improves with volume recycled). Limits choice of material
	Limit difficult to recycle material	Recyclable plastic often has more expensive tooling than less recyclable plastic. It is important to increase the volume of these types to stimulate the recycling market.
	Use recycled material in new vehicles	Recycled materials rarely give a reliable supply. Greater use of recyclate produces risk to the material supply chain
		Recycled materials are rarely cheaper than virgin materials at same quality level
	Cost benefit of recyclability	If suppliers are not brought into the design circle at the beginning, opportunities to reduce negative impacts will be lost. They understand the materials markets better, can suggest better alternatives & bring experience from other sectors.

Source: Tele-interviews with vehicle manufacturers' materials engineers (Sept 2000)

6.4 Summary

For the 3DayCar, there are only a few issues that conflict with the general aims required. The extent to which positive aspects will compensate for negative ones depends on the approach taken by the manufacturer. Collaboration with suppliers at the design stage is crucial to the success of a manufacturer in producing a 3DayCar that is recyclable.

- DFR can reduce part counts and drive simpler designs e.g. homologated bumpers and cockpits, which can benefit the 3DayCar.
- Composites and in-mould coverings make vehicle assembly easier, but will conflict with recycling unless totally compatible materials are used.
- Recycled material is now equal to virgin material in terms of quality and cost, but the market tends to be more volatile in terms of price and supply. The quantity of recycled material used in cars is currently low[2] and greater volumes will reduce supply volatility. However, the corresponding increase in demand means that a risk to lean material supply will still exist because of variations in availability.

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GM Environmental Report

Keoleian, G.A. and D. Menerey (1993) Life-cycle design guidance manual: Environmental requirements of the product system. Cincinnati, OH: Risk Reduction Engineering Laboratory, Office of Research and Development, U.S.EPA.

Renault SA – Environmental Report 1999

VW Environmental Report 1999

[2] For example with the Volvo S80 this is 1.3% of the weight of the vehicle. The types of components which are currently sourced from recyclate are air ducts, parcel shelves, battery cases, air intake grills, air cleaner covers, camshaft carriers, fender liners, instrument housing, spoiler, tail lamps, wiring ducts, interior trim, carpet padding and sound proofing. These constitute a fairly low proportion of the bought in cost i.e. less than 5% (using Figure 3 pg.. as a basis), therefore a low risk in terms of value, but only takes loss of supply of one component, such as a spoiler or parcel shelf for a short period to stop supply to the end customer.

7 Cost

"There has only been one year since 1950 that our company hasn't shown a return on investment for our shareholders!" (Anon)

7.1 The model

The objective of this Chapter is to construct a model that examines the cost implication of a build-to-order (BTO) production system. The model in Appendix A identifies overall profit and cost factors, comparing variable and fixed costs of a 'conventional' and 'future' state. Its aim over the project is to identify key areas of vehicle design and production technology that will maximise profits, in this case to compare conventional with alternative body and plant structures.

This is a long term project which will continue beyond 'Vehicle Design' and into 'Cells Lines and Tooling' research in 2001. It may also involve other research streams such as Environment and Finance, and aims to feedback results to the 3DC simulation.

7.2 Current concerns

There are already a number of concerns surrounding current production[1]:

- Stocking cars from complex ranges is highly inefficient (there is typically 50 to 60 days of finished vehicles in the distribution system):
    - Stock held is unlikely to match customer demand unless an effective distribution centre is operated.
    - Sales are lost by the slow response if the vehicle required is not in stock.
    - Space and money costs are substantial.
    - 'Switch selling' to alternative specification reduces customer satisfaction, i e: cars are not 'factory fresh'.
- Volume car lines are very competitive with considerable profit pressures.
- Present manufacturing systems are very unresponsive. It takes, on average, around 40 days from order to delivery (OTD).
- Conventional production provides a number of obstacles to smooth order flow:
    - Average colour batch size in Paint: 12 cars
    - Paint shop quality: 28% of cars reworked, of which 4% go off-line.
    - The disruption from the above to daily production means that daily schedule reliability varies between 65 to 90% of individual orders produced on the intended day
    - IT legacy, 4 to 5 days are spent in overnight batch processing for each order and there is a lack of system integration & standards.

Therefore, when considering adopting a BTO production approach, the following factors must be considered in terms of maximising product line profitability:

- Reducing investment for new product:

[1] This section was developed from discussions held with Prof. J Brown

- Lowers overall risk
- Enables quicker, more frequent, product updates
- Enables low volume, high margin niche products

- Lowering variable and fixed costs.

- Enabling true BTO with minimum delay and maximum mix flexibility.
  - Maximises sales
  - Minimises finished vehicle stock with associated potential savings of 5 to 10% of vehicle price

Some of the above points have already been included in this report. However, before comparing the models, it is important to examine the significance of the trade-off between variable and fixed costs.

7.3 Variable and fixed cost

Traditionally, alternative construction technology such as spaceframes only has a place in low to mid-volume / high margin 'niche' models. This is because the variable cost tends to be high, traditionally between 2-5 times more expensive depending on the component design and processing method. (However, this differential has reduced given advances in technology). Choosing whether to adopt alternative construction is a 'total cost versus volume' decision. The cycle time for producing a component depends on the amount spent on tooling: the greater the investment, the quicker the part is produced and therefore the lower the variable cost. Traditionally, with a low volume model one cannot afford the associated high fixed tooling and investment costs.

A current solution to this is to use a modular construction technique, such as spaceframes, but pay a higher variable cost in production as a result. Depending on the price positioning of the product in the market and what the affordable business structure assumptions are, one has to decide on whether to adopt a 'high variable / low tooling cost' approach (eg: spaceframes) or the 'low variable / high tooling cost' approach (eg: monocoque).[1]

The question for 3DC is whether an alternative method of body construction, such as independent body and panels (IBP), with the potential to eliminate the paint shop and many of the reliability and scheduling problems that currently disrupt production, can offer a cost effective BTO environment? This is a complex issue. Whilst IBP may increase variable costs, this is not inconsistent with higher profits because of other benefits that it could bring: minimising finished stocks, component sharing across platforms and quicker, more frequent product updates.

7.4 The conventional and future models

Two models are considered in order to give an overview of the relevant costs (Appendix A, p43-44).

The 'conventional' model reflects the current state of automotive production, with a hierarchical supplier structure, fixed / sequential assembly plant and a network of distribution centres and dealerships. Fixed costs include £400 million for the total facility /site, of which £100 million is accounted for by the Paint shop and body stores. Downstream of production, assuming the average vehicle price is £9000, it estimates that *£225 million* of finished stock is held in the distribution pipeline.

[1] From discussions with a Senior Automotive Engineer.

The ‘future’ model assumes that a fully integrated logistics network will be in operation, from component supply to vehicle delivery. In this example the paint shop is eliminated, although single coat body painting remains, with exterior body colour provided by moulded panels attached during final assembly. It assumes a BTO environment has been achieved, therefore distribution centres have been eliminated. If finished stocks can be reduced to 10 days for cars held in outbound logistics and dealer showrooms, the value of stock reduces by £180 million.

However, the future model requires the additional costs of plastic panels. In theory, despite the advantages over the conventional model in terms of dramatically reducing finished car stocks, both variable and fixed costs will increase, as shown in Figure 11. This gives a cost comparison of the variable costs of componentry and the fixed costs of body production, paint and vehicle assembly. These show increases of 2.5% in fixed costs and 7.4% in variable costs in moving from the conventional to the future models, for this element of production.

Figure 11 Variable & fixed cost comparison

Variable costs (£)

Conventional:		Future:	
BIW	700	**BIW**	700
Powertrain	1300	**Powertrain**	1300
Front end	500	**Front end**	500
Rear end	300	**Rear end**	300
Cockpit	500	**Cockpit**	500
Interior trim	1800	**Interior trim**	1800
Exterior trim	300	**Exterior trim**	300
		Plastic panels	***400***
Total:	5400	Total:	5800

Fixed costs (£ million)

Conventional:		Future:	
Press shop	60	**Press shop**	60
Tooling	60	**Tooling**	50
Weld shop	90	**Weld shop**	90
BIW store	10	**‘Single’ Paint shop**	70
Paint shop	80	**PBS**	10
PBS	10	***Injection moulding eq.***	***30***
Final assembly	80	**Final assembly**	80
Inspection	10	**Inspection**	10
Total:	400	Total:	410

Source: various

All costs shown and subsequent analysis is extremely approximate and subject to wide variation in magnitude and definition. The analysis is purely intended to give a general indication of the magnitude of the factors involved in future decisions on body technology. These will be refined as feasible in the last year of 3DayCar research.

The breakdown of Manufacturing costs presented by Professor Jonathan Brown at the 3DayCar Conference in June 2000 are shown in Figure 12.

Figure 12 Breakdown of manufacturing costs

TOTAL MANUFACTURER COSTS		100
Fixed Costs		27
Sales & Marketing	8	
Depreciation	5	
Other Manufacturing Fixed	5	
R&D	5	
Other	4	
Variable Costs		73
Warranty	3	
Sales & marketing	4	
Paint Trim & Final Ass'y	5	
Powertrain & Components	10	
Bought Out Parts	51	

Using this breakdown and vehicle cost breakdowns in Figure 3 of Section 1.5 of this report, the following conclusions can be drawn expressed as a percentage of total manufacturer costs.

Extra costs of the 'future' against the 'conventional' scenario consist of:

- Maximum of 0.2% in fixed costs
- Maximum of 5.0% in variable costs
- Increased stock held in components. The overall cost of logistics is approximately 15% of total manufacturer cost and any changes in stock level are likely to contribute no more than 2%. However, the 3DayCar team believe that moving to a future model will cause a minimal increase in stock levels across the *total* supply chain. This will be demonstrated by the 3DC simulation.

The total extra cost is thus a maximum of around 7%.

Savings from the future model include:

- Reduction in distribution costs of 6-10% of recommended retail price or 7-12% of total manufacturer cost assuming a 20% margin between manufacturer cost and retail price to allow for manufacturer profit and dealer margin
- Reduction in the cost of product change in terms of bodies which involves:
  - Longer life of machinery
  - More frequent product changes with increased total sales as the potential
  - Shorter changeover periods with subsequent reduction in production cost
  - Less engineering development work on product change

  This could save up to 5% of total manufacturer cost given higher sales volumes.

The potential savings are thus of the order of 12 -17% in the above areas, although a significant proportion of the distribution cost savings can be achieved with a conventional monocoque body and a large painted body store.

While this is a simplistic example of a complicated subject, it does show overall potential savings of 5-10% in moving to BTO with a future IBP strategy. The excess cost of alternative body technology is bound to decrease over time with increased research and development focus, and thus IBP technology must be taken seriously by the motor industry, especially as it has potential environmental benefit in terms of body weight and thus fuel consumption.

7.5 Summary

- Evaluating the cost potential benefits of any technological change which is of interest to 3DayCar cannot be limited to consideration of variable costs or differences in fixed cost over one product alone, but must take account of any other factors which are affected by the change in technology. For instance, when considering the impact of individual vehicle design technologies such as modular frames and plastic panels, the following must be assessed:

    - Lower total supply chain operating costs, especially associated with minimising finished vehicle stock through the increased ability to operate rapid BTO.
    - Reduced the cost of product change, including investment for new product and fixed costs being spread over more product cycles

- While the cost model is simplistic, significant savings over current processes, of the order of 5-10%, can be achieved by adopting a rapid BTO approach using IBP strategy.

8 Conclusion

Figure 13 assesses the magnitude of impact on 3DayCar of the key technologies discussed during this report and the likelihood of their impact by 2010.

Figure 13 The technological opportunities for rapid BTO by 2010

Technology	3DC impact	Description of impact	Likelihood of impact by 2010
1. Spaceframes	✓	De-couples Body. Modular body construction allows one set of parts to build saloon, hatch, & estate. Partial eg: 'Defender' series chassis.	1
2. Independent Body and Panels (IBP)	✓	De-couples Paint from production. Ext. Panels are painted seperately. Eg: GM Saturn EV-1.	2
2a. " thermoplastic panels	✓	As above, but use of moulded coloured plastic panels means paint shop and quality / reliability issues virtually eliminated. Eg: DC Smart.	2
3. Vacuum pressure al. Die- casting	✓	Reduce body construction complexity	1
4. Glazed roof panels / roof modules	✓	Eliminates sunroof option in BIW	3
5. Hydro-forming	✓	Reduces body pressing complexity	2
6. Platforms	✓	Increase parts sharing and standardisation.	3
7. Hybrid electric vehicles	X	Two powertrains: increased complexity	1
8. Direct injection diesel	✓	Little impact on complexity, but core skills & technology may shift to suppliers, eg: Bosch.	3
9. Fuel Cells	-	Currently all niche models: Zafira, A-class & P2000. Volume production expected well beyond 2010.	1
10. Modules	✓	Roof module reduces BIW options. All modules reduce complexity & leadtime in prod'n. 'Mix & match' / mass customisation.	3
11. Telematics	✓/ X	Whilst offering more variety to the customer, will increase vehicle complexity.	3
12. Multiplex (MUX) & Cable area networks (CAN)	✓	Significantly reduces current wiring harness complexity. Potential for 'plug and play' facility.	3
13. X-by-wire	✓	Less mechanical parts required through electrical control, but expected 2008.	2
14. Electric control units (ECU) and microprocessors	✓	Whilst ECU content will increase, the functional characteristics of the vehicle will be defined more by the software programming inside.	3
15. Remote diagnostics	-	Technology is available, but legislative issues will take many years to be established.	1
16. Design for Recyclability	✓/ X	Will both simplify component assemblies, but will also require more 'break points', which may affect assembly leadtime. Volatile material markets will affect supply capability.	3

Very positive impact: ✓ *Positive impact*: ✓ *No impact*: - *Negative impact*: X *Positive & negative impact*: ✓/ X
Likelihood: 1: *unlikely* 2: *quite likely* 3: *very likely*

This research examines the technological opportunities to enable rapid build-to-order (BTO). It highlights the significance of vehicle complexity and variety in reducing order-to-delivery (OTD) by means of component reduction, sharing / standardisation and mass customisation. It shows specific areas of vehicle design, such as body construction, as being fundamental to the entire nature of the production process and has developed the work on spaceframes, adding independent body and panels (IBP) as a significant construction classification.

There are strong links between complexity, platforms and modules. A rapid BTO environment is enabled by common platform strategies across models and brands, which increase parts sharing. Modules, the basic unit of the platform concept, benefit 3DC by removing complex assemblies from the line, thus reducing production leadtime. However, responsibility for delivery and holding stocks is shifted towards suppliers. The roof module is particularly relevant to 3DC as it eliminates the sunroof option at BIW. Current concepts for painted door and interior modules will become common practice for many manufacturers, who can offer a 'mix and match' service for customers.

Despite concerns raised here over brand differentiation and the ability to maintain price differentials, in the future a brand is likely to be defined more by electronics than mechanical functions contained in the vehicle. The growing presence of electrical enablers such as MUX, CAN & X-by-wire will provide a rich source of mass customisation, offering the flexibility of 'plug and play' for new products and services. This could lead to new concepts such as vehicle 'refreshing', which will extend the lifecycle and maximise profit opportunity.

Vehicle design faces a challenge in the form of new legislation, not only as an inhibitor to technological development such as speech recognition and collision avoidance systems, but in terms of the requirement from Brussels for manufacturers to comply with Design for Recyclability regulations by 2006. Will the future of product design be driven by rapid BTO and recent advances in vehicle body construction, telematics and lifecycle refreshing?

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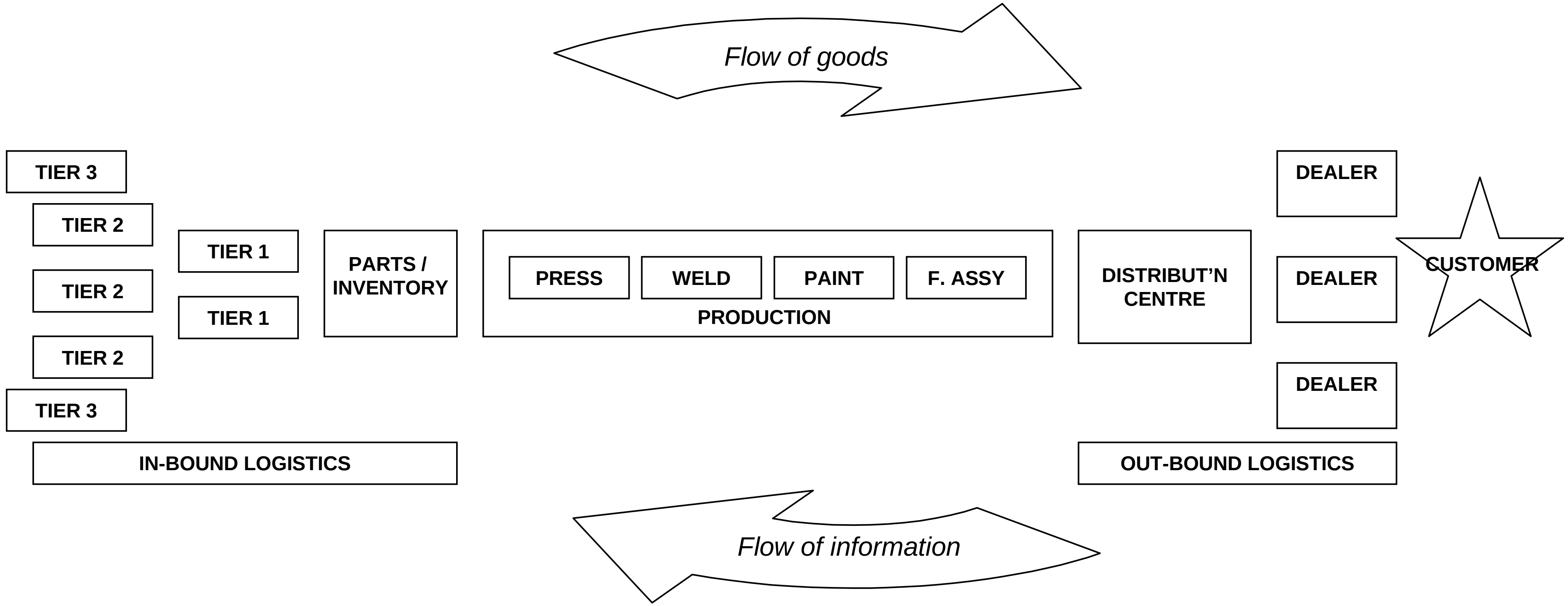
Appendix A
Figure A1

'Conventional' cost model

Assumptions: vehicle price: **£9,000**. Total production pa: 150,000 (500 cars per day). **50 days** stock held in distribution / outbound logistics / dealers.



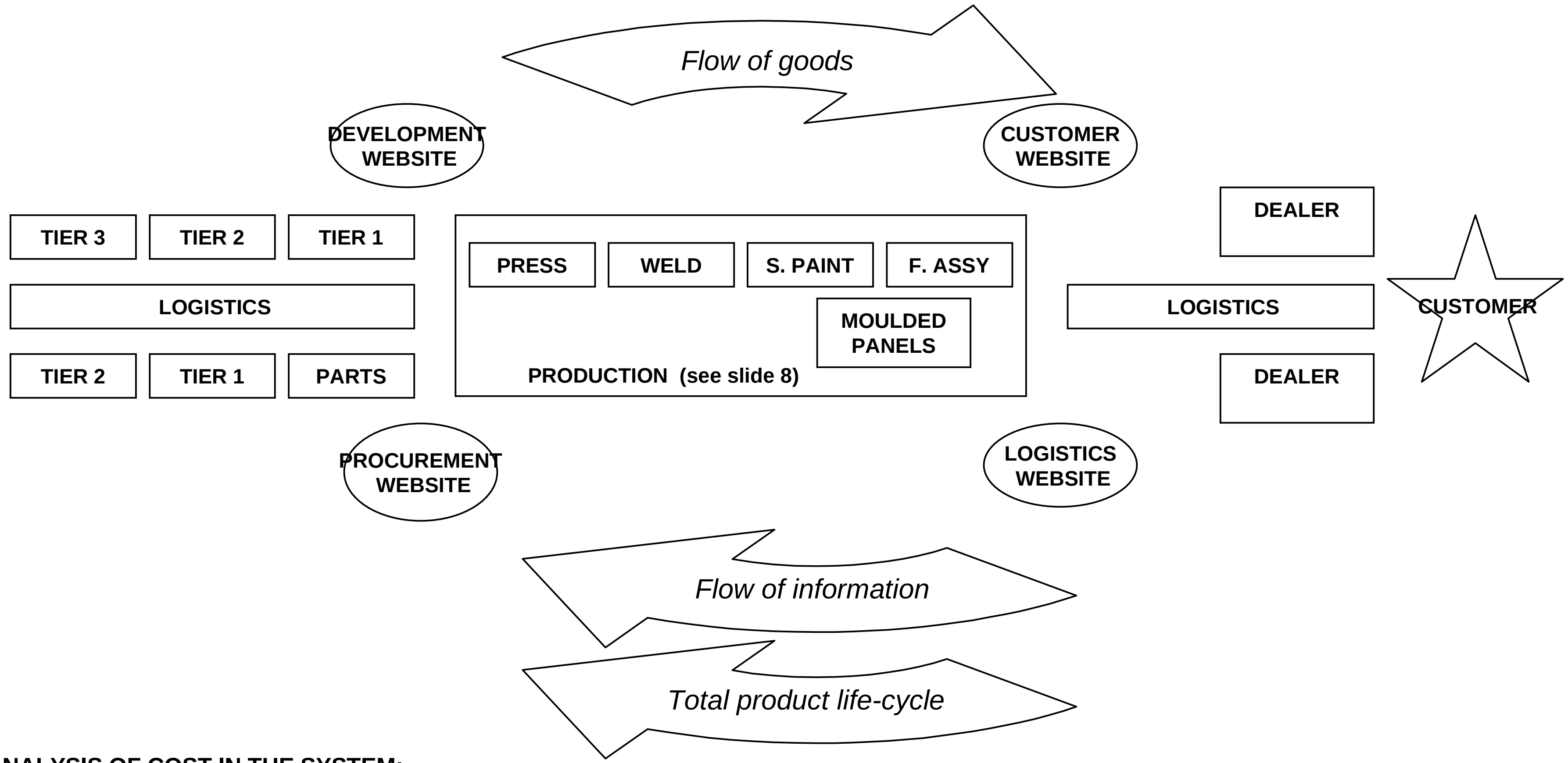
ANALYSIS OF COST IN THE SYSTEM:

VARIABLE COST (Parts & finished stock)	-	Steel panels (2 days / 1000 complete sets): **£300,000**	**£225m** (finished cars) in pipeline
FIXED COST	-	Tooling costs: **£60m**. Conventional Paint shop / BIW & Painted body stores: **£100m**. Total site / facility: **£400m**	-

Appendix A
Figure A2

‘Future’ cost model

Assumptions: vehicle price: **£9,000. 10 days** stock held in outbound logistics / dealers.



ANALYSIS OF COST IN THE SYSTEM:

VARIABLE COST	More parts required..?	Steel panels: **£300,000** Plus cost of plastic panels **£ ..?**	**£45m** in pipeline
FIXED COST	-	Tooling cost: **£60m**. Inj’n moulding tooling & machinery: **£30m** ‘Single colour’ Paint shop / small body stores: **£70m**	-

Appendix B, Figure B1

Table showing current recycling activity in 7 vehicle manufacturers

Company	General	Design Criteria	Recycled material used	% recycled
BMW	BMW was one of the first auto manufacturers to employ design for recycling in their new cars. This started as early as 1990 when they first introduced standards for recycling cars and designing components, which could be recycled. Since 1991 all components have to be subject to the recycling standard 113 99.0. BMW are involved in the 'Together for Recycling' partnership with Renault and Fiat to set up recycling centres for their cars of which there are around 200 so far in Germany. .	The front head lamp on the 3 series which can be completely dismantled without any destruction so that each component could be reused. The Z3 air filter housing is made of polypropylene which can be completely recycled, the filter can removed and replaced as no glue is used.	Instrument panel - the warm air duct is made of thermoplastic SMA-GF10 recyclate The core of the rear parcel shelf is made of PUR recyclate.	
Renault	Renault also is one of the partners in the 'Together for recycling' partnership with BMW, Fiat and Rover. Through this they have established 270 dismantling centres in French territories which comply with strict operating standards needed for ELV processing	Renault have developed specific design criteria for recycling and recovery **All plastics are to be marked according to the right codes e.g. PE, PMMA etc** - All plastics parts are now marked with ISO codes. **Reduce the number of components mounting points and standardise mounting types for similar types of component,** - Standardised component fasteners are now used for quick assembly and disassembly methods. **Use quick release fasteners (clips and clamps),** - Clio II fasteners were modified for easier recycling **Improve access to mounting points** - on the new Clio a clip under the dashboard cowling was eliminated to facilitate easier dismantling of the windscreen pillar. **Limit number of materials used for the same purpose and if more than one material for a component then choose compatible materials** - On the Clio II side mouldings the clips of different material were difficult to remove so on the new Clio these were integrated into the polypropylene moulding. **Specify materials for use in current recycling systems - prefer materials which can be currently recycled without major new recycling infrastructure.** **Control and limit materials which cannot be incinerated (although clause taken out of EU Directive to consider this route).** **Drain points to be at lowest points of any fluid reservoirs.**	For example the Kangoo is built with 26 recyclable parts apart from the metal components which are already removed.	
VW	VW helped open a pilot ASR processing plant with the VDA, the regional Waste Institute and the German Ministry for the			

	Environment.			
Ford	The Ford Motor Company have a number of teams looking into vehicle recycling (US-RAT and E-RAT). The use of recycled materials is being intensively investigated both in the US and		Ford currently has 205 non-metallic parts in production made of recycled material. This saves 14,000 of landfill waste annually with it being turned into cars parts instead. Europe Examples of the production parts made of recycled material are battery cases made from recycled battery cases (a closed loop system) and air intake grills made from old bumpers.	. The Ford Focus is purported to be 85% recyclable and contains 44 parts made of non-metallic recycled material.
GM/ Vauxhall	These standards are used globally, wherever the cars are manufactured or marketed.	Substances used in cars have been strictly controlled through material specifications published in 1994 also. GM issued guidelines to suppliers in 1994 to calculate recyclability	• Air cleaner cover - all models • Camshaft carrier cover - Corsa, Calibra and Vectra • Fender liner - all models • Instrument cluster housing - Vectra and Calibra • Rear spoiler carrier - Corsa and Vectra • Tail lamps - all vehicles • Wiring ducts - all vehicles	
Volvo	The main areas of volvo activity are labelling of plastics, dismantling standards and use of recycled plastics.	Guidelines for suppliers for the recyclability of their parts have been issued. All plastics above 50g are labelled.	The S80 contains 21.4kg of recycled plastic	
Fiat	Launched the Fare project in 1992 to handle all issues relating to automotive recycling	Specific rules and procedures to be applied during design phase Specific recycling objective set for all new models and components.	21,720 tons of glass used as bottles 6144 tons of bumpers used as air ducts, interior trim 7424 tons of seat padding used as carpet padding and sound proofing	