The 3DayCar Component Supplier Study –
Investigating the Implications of Responsive Vehicle Supply on the Component Supply Chain

by
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February 2002
Executive Summary

Component supply has a critical enabling and therefore potentially inhibiting role in more responsive vehicle supply. The conclusion of the research is that the ability of component suppliers to be responsive is very much related to their individual circumstances. However, inability to perform is much more related to planning information and lead times to change, especially late amendments, rather than delivery performance to the vehicle manufacturer.

The actual on-time delivery performance has been benchmarked at 99% or a failure rate of 10,100 parts per million, which is high - but not in itself an inhibitor since delivery frequencies are, on average, more than once per day, although specific components might still pose a problem.

Several factors have been identified as inhibitors to responsive component supply, yet these are – due to the great diversity of components – contingent upon the type of component and various external factors, such as the geographical distance and logistics arrangements. Hence the main conclusion reached is that the ability of suppliers to support responsive vehicle supply is contingent upon their particular inter- and intra-company relationships. Whilst a theoretical model for the different types of components can be developed, ultimately a component-by-component analysis is required to determine the exact impact in each individual case, as suggested by Cooper and Griffiths (1994).

Nevertheless, the following generic inhibitors have been identified:

- Demand variability is considered the main constraint, yet the survey data only revealed limited variability between actual schedules and forecasts. However, as the survey data covered the overall volume demand, variability at part level was not covered in this analysis, yet could pose difficulties.

- Frequent late amendments of the actual call-offs occur – on average every other day. These late amendments occur either due to parallel interactions, whereby problems with one supplier affect other suppliers (Wilding, 1997), line problems at the assembly plant, or changes in overall demand. Further research should address this issue in order to determine the root causes for these distortions and strategies developed in order to mitigate the adverse impact on the component supply chain. These late amendments are particularly damaging due to the short notice given, and are seen as the main reason for the current uncertainty and lack of confidence in the demand information provided. This demand distortion is passed on to the second tier suppliers, although there is case evidence that drastic demand amplification can occur between the vehicle manufacturer and the second tier supplier due to batch-driven production planning systems at the first tier level.

- Mix flexibility is more of an issue than volume flexibility – a fact confirmed by the process mapping, which revealed large batch sizes, in particular in pre-assembly stages, which inhibit the ability to react to changes in the short term. The reason is that in many cases the pre-assembly process stages are de-coupled from the actual assembly through a different production control system, generally an MRP system.

In terms of volume flexibility, i.e. the ability to alter capacity in response to changing requirements, the survey indicated a general flexibility both in terms of increasing current capacity utilisation as well as the ability to increase the available production time (either through overtime or additional shifts). It must be remembered, however, that it is the worst supplier in the system and not the average that determines the ability to increase the throughput of the system (Goldratt, 1990).
While capacity increases are generally feasible in the short term, they are often not sustainable over a longer period of time due to a lack of qualified labour, or the prohibitive cost of such labour flexibility.

- First tier suppliers themselves have to deal with significant sourcing complexity in terms of the number of second tier suppliers and associated materials and parts. The availability of materials and components was classified as a main constraint to first tier suppliers, because long order lead-times and distances are common with second tier suppliers play the most important role. In particular, the raw material suppliers show little flexibility in terms of their order lead-time, which has been criticised previously as having an adverse effect on supply chain performance (Hines et al., 2000).

Summing up, the three main inhibitors found in the component supply subsystem are the impacts of demand variability, the batch-driven production systems, and long supply lead-times and distances from the second tier supplier. Also, in several cases the reliability of production was an issue, as for example in the case of engine plants. These factors are all mirrored in – and to a large extent the cause of – the high levels of inventory found in supply chains. The finished goods inventory largely serves as a buffer against demand and production variability, with cover often duplicated at both the supplier and the manufacturer. The high WIP inventories are a consequence of the large batches operated in pre-assembly production stages, and the high raw material stocks and component inventory are due to the inflexibility of the second tier suppliers.

All the areas mentioned need to be addressed if a 3DayCar is to be successfully implemented without increases in component stock. However, there is a lot of stock which can be reduced in the first tier component supplier, particularly before production of the component within the current system. A model describing the implications on the component supply chain has been developed for the major types of component, dependent on the lead time of sourcing, as a guide to the development of a 3DayCar strategy. It is based around the critical response lead time of 36 hours, being the time before entry to the final assembly line that the precise sequence is defined on an hourly basis by the vehicle manufacturer. All components, including a maximum number of high value and complex ones, which are produced or assembled within this lead time operate on a basically stockless JIT process, whereas stock has to be held for components with a longer lead time than 36 hours. A question mark hence hangs over the viability of long distance suppliers due to their probable inflexibility and the excess cost of stock as well as transport. This brings 3DayCar thinking into conflict with global sourcing.

Research using the simulation has shown that such a system can operate on a 3DayCar basis without any significant increase in stock, through better planning information shared in a co-ordinated manner between all relevant parties. While significant changes have to be introduced, component suppliers can certainly become enablers of a 3DayCar supply process rather than inhibitors.

Acknowledgements

The author would like to thank all participating companies for the time and effort spent in support of this study. Also, the support of the 3DayCar team in completing the survey is gratefully acknowledged.
1 Introduction

‘The underlying problem here is that once information ages, it loses value. ... old data causes amplifications, delay and overhead. The only way out of this disjointed supply system between companies is to compress information flow time so that the information circulating through the system is fresh and meaningful.’

George Stalk Jr. and Thomas M. Hout

1.1 Research Problem

A frequent point made throughout the 3DayCar research has been the enabling (or potentially inhibiting) function of the component supply subsystem for more responsive order fulfilment of the overall vehicle supply system. In other words, if the component suppliers cannot provide the right components in a timely fashion, it is very unlikely that the vehicle manufacturers will be able to progress far towards a three day car.

‘Component suppliers’ however do not exist as a homogenous entity, but in fact comprise of a great number of different suppliers based in very different technologies – from steel, glass, and plastics to rubber and electronics. On average, 2,000 - 4,000 components are bought from suppliers for each vehicle, accounting for 60-75% of the overall value of the vehicle. And it is this value and diversity that effectively rules out the ‘assemble-to-order’ concept so successfully used by Dell Computers, for example, whereby a component buffer is used to enable responsive order fulfilment to the customer. This buffering approach is only half the solution, as previously discussed (Holweg and Pil, 2001), and can only be used by Dell due to a low component variety which is several orders of magnitude below the variety found in the automotive industry.

Holding inventory therefore is not the answer to enable responsiveness in the auto supply chain. A ‘three-day car’ relies on capable component suppliers, and the question arises whether suppliers are currently capable of supporting responsive build-to-order strategies. The main research question for this report is therefore:

Which generic factors inhibit responsive component supply?

This was investigated through a series of interviews and mapping exercises, and a questionnaire survey. A brief discussion of current trends, previous research in the automotive supply chain, and an outline of the methodology used are given below as an introduction to the research findings.

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1 The underlying report forms the last in a series of Systems Stream reports, covering the order fulfilment process, product variety, logistics operations and historic aspects of vehicle supply in the UK. Further information on the previous results & reports and on the 3DayCar programme in general can be found on the 3DayCar Programme pages at www.3daycar.com.
1.2 Current Trends

While technological trends such as alternative body structures, 42V-systems, and the increase in electronic content in the vehicle have been the centre of much discussion recently, logistics trends towards modularisation and outsourcing and the resulting re-tiering of the supply chain (Turnbull et al., 1993; Cousins 1999), together with the impacts of global sourcing (Das and Abdel-Malek, 2001), have also warranted much attention among the cognescenti.

The impact of modular component structures on the responsiveness of the overall vehicle supply system was not the focus of this study, being beyond the remits. Nevertheless, potential positive impacts of modularisation are:

- **reduced complexity** in the vehicle build scheduling and capacity planning
- **less flexibility constraints** and better control over them due to increased visibility
- **fewer points of supply responsibility** with the vehicle manufacturer potentially enable better communication amongst the players in the system.

Amongst the vehicle manufacturers, there is no consistent trend towards modularity. Whereas some manufacturers have committed themselves to a general modular structure shared across many brands, others have revised their strategies and ‘broken up’ some of their modules into several smaller modules. This is because some vehicle manufacturers are increasingly concerned about outsourcing responsibility for design and production of modules, since first tier suppliers are generally tasked with the assembly of these modules. A key reason has to be seen in the loss of power, but also the loss of knowledge in component design and manufacture, which is critical input into the vehicle design process. Interestingly, research by the International Motor Vehicle Program concluded that the current labour-cost differential between the vehicle manufacturer and suppliers is the main driver for modularity and outsourcing, and not the operational benefits such as responsiveness (Warburton, 2000).

Another major trend has been towards global sourcing of components, generally based on lower production cost in low wage countries. Due to the inevitable logistics lead-times however, a move towards build-to-order puts a serious question mark over global sourcing in general. This point will be further discussed in the conclusion of this report using the model proposed on the basis of the findings of this study.

1.3 Previous Research in the Automotive Component Supply Chain

The automotive component supply industry has been widely researched. In fact, much of the generic supplier relationship literature and modelling has been derived from the automotive industry (e.g. Lamming, 1993; Hines, 1994). Several core themes within this research can be identified. The most widely discussed issue is the shift from adversarial, price-driven to collaborative partnership-driven relationships. A wide range of research exists, and evidence has been reported from the UK (Turnbull et al., 1992; Ali, Smith et al., 1997), the US (Helper, 1991), comparative studies with Japan (Cusumano and Takeishi, 1991; Hines, 1998), Spain (Gonzalez-Benito and Dale, 2001), Italy (Calabrese, 2000), Turkey (Gules et al., 1997), and large-scale benchmarking studies have been issued (Andersen Consulting, 1993, 1994). The overall conclusions highlight the trends towards close collaborative relationships, and their benefits including the positive impacts on performance and, indeed, on new product development (Croom, 2001).
The importance of supplier flexibility and responsiveness within a build-to-order framework has been pointed out by Hertz et al. (2001) in the case of Volvo, yet overall the area has rarely been discussed. Jayaram et al. (1999) studied the application of time-based competition in the US supplier industry. They apply measures across key business processes such as delivery speed, new product development time, delivery reliability, new product introduction lead-time, and manufacturing lead-time. Hendrick et al. (1996), for example, highlight Purchasing’s critical role in time-based strategies, Kirtley-Paine and Southey (2000) conclude from their work at Jaguar that flexibility is not presently seen as an issue in the sourcing process:

‘The ability of a first tier supplier to manage the supply chain is not taken into consideration during the sourcing process at Jaguar, nor is the ability, capability or expertise of the supply function. This is in direct contrast with other functional skills such as engineering, which are considered and rated as part of the sourcing process.’ (p.317)

Very few explicit studies have been carried out investigating what factors determine the ability of a supplier to respond to changing requirements. Harrison (1996), for example, links responsiveness to demand variability in his study of one UK component supplier, a notion also followed by Griffiths and Margetts (2000). Das and Abdel-Malek (2001) have proposed a more comprehensive mathematical model of supplier flexibility, yet only propose a conceptual model without applying it. Furthermore, their model seems constrained by arbitrary assumptions and was therefore not considered. Stalk (1988) describes Toyota’s initiative in reducing their suppliers’ response lead-times from 15 to 3 days in Japan.

2 Methodology

2.1 Introduction

The research presented in this report is divided into two sections. The first section discusses the key findings of the process mapping, showing two examples – a subassembly supplier and an engine plant. These two examples are chosen as representative of a typical subassembly and a critical high-value, high-complexity item, respectively. In total, 5 mapping workshops have been carried out, complemented by 14 semi-structured interviews and 8 plant tours, including three supplier parks. Furthermore, the demand and supply dynamics in the supply chain have been analysed in the case of an electronics supplier, using the ‘demand amplification mapping’ tool suggested by Hines and Rich (1997).

The second section presents the findings of a survey of 17 suppliers to UK assembly operations, two of which are located in mainland Europe and the remainder in the UK.

2 In total, 18 supplier parks were operational in Europe in 2000.
2.2 Assessing Supplier Responsiveness

Few specific approaches or frameworks regarding supplier flexibility or responsiveness have been proposed so far, yet the need or ability to provide the right components of high quality in short lead-times is fully recognised. Several factors influence this ability.

The variability of the incoming demand signal from the manufacturer is seen as a crucial enabler for smooth and stable production – a factor generally mentioned in conjunction with inventory levels (Harrison, 1996; Hines, 1998). A low level of inventory is seen as a key performance indicator for the alignment between supplier and manufacturer. As Griffiths and Margetts (2000, p.156) state:

‘Suppliers are continually being expected to deliver in smaller, more frequent batches. Achieving these response times, and maintaining efficiency, inevitably involves holding stock. The more flexible a supplier is, the less safety stock that needs to be held.’

With a similar approach, production batch sizes and delivery lead-times and frequencies are discussed (Sako et al., 1994; Hines, 1998; Jayaram et al., 1999; Griffiths and Margetts, 2000). Further aspects of research include product quality (Turnbull et al., 1992) and parts variety (Hines, 1998).

It is believed that in isolation none of the above factors can provide a sufficient indication of response capabilities of suppliers – a view strongly endorsed by the variety of factors considered by the studies reviewed above. For the purpose of this research, the key factors were assembled into a framework outlined in figure 1. As can be seen, the framework extends beyond the boundaries of the first tier supplier, and includes the critical inputs and outputs in relation to the vehicle manufacturer on the one side, often involving the inbound logistics function, and second tier suppliers on the other. On the manufacturer side, the key input is the demand information provided, and the outputs are delivery frequency, lead-times, parts variety and delivery performance. On the second tier supply side, the key inputs are parts variety and order lead-times as a measure for material availability, a point strongly mentioned as a constraint in several interviews at first tier suppliers.

![Figure 1: Framework for Supplier Survey](image)
2.3 Component Segmentation

The complexity of the automotive industry becomes particularly apparent at the interface between vehicle manufacturer and first tier supplier. On average, vehicle manufacturers quote between 2,000 and 4,000 components as being sourced from their first tier suppliers, with similar figures being quoted in the literature (e.g. Batchelor, 2000). The number of suppliers per plant depends on several factors: the sourcing strategy (single or multiple sourcing), the degree of modularisation and outsourcing, and the part numbers sourced per supplier. During the process mapping research, for example, Nissan quoted 204 European suppliers (plus the Japanese suppliers for engines, transmissions, etc.), whereas Ford of Europe claims to have reduced the number of key suppliers in Europe from 900 in 1992 to 650 by 1995. Specialist manufacturers show similar numbers; Jaguar for example had 407 suppliers in 1999 (Kirtley-Paine and Southey, 2000).

Although there is no doubt about the general trend towards a reduction in the supply base as discussed for almost a decade (e.g. Turnbull et al., 1993), the overall sourcing complexity is still substantial. When Ford started the production of the Ka in Valencia, the number of parts handled by assembly workers fell from 3,000 to 1,200 compared to the previous Fiesta model. Also, the total assembly time fell by 25%, since module assembly was outsourced to suppliers in the supplier park that was opened at the same time.

The current parts complexity and number of suppliers posed a significant challenge for the design of research, as a comprehensive coverage of either all types of parts or even the most valuable parts was infeasible. While the breakdown of the total cost of the vehicle into its major constituent parts was not available from the vehicle manufacturers for obvious commercial reasons, estimates provided by Goldman Sachs for a compact-class (C-segment) vehicle as shown in figure 2, illustrate the great spread of component value. Very similar estimates have also been made by Wells and Nieuwenhuis (2001).

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**Figure 2: Value of Vehicle Components**

*Adjusted to include raw material, paint and % of stamping / pressing costs. Source: Adapted from Goldman Sachs*
It was finally decided to divide the parts of a vehicle into five component categories, similar to a cluster sampling approach (Saunders et al. 1997). Segmentation has also been used by Turnbull et al. (1993), splitting automotive components into bulky, system, generic, trim and wiring related parts.

This fulfilled two purposes. First, segmentation allows for a purposeful sampling of suppliers without distorting the picture in terms of vehicle composition. Second, it allows for analysis of the whole sample, as well as for comparison of specific segments of components. It was the latter which strongly influenced the type of segmentation chosen. Initially, a value-contribution approach was considered, yet rejected as insufficient costing data was available and the different degrees of modularisation did not permit a valid comparison across vehicles. Instead, five categories based on volume and mix sensitivity were chosen (see table 1).

<table>
<thead>
<tr>
<th>Component Segment</th>
<th>Description</th>
<th>Examples</th>
<th>Sensitivity of Component Segment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-specific</td>
<td>Components that can be installed in several different products, even across brands</td>
<td>Batteries, spark-plugs, wipers and engines (!)</td>
<td>Sensitivity to overall market rather than model fluctuations</td>
</tr>
<tr>
<td>Standard</td>
<td>Model specific components. Complexity is low, component consists of generally one material only and does not need any or only few assembly operations (bolts etc. excepted). Applicability ranges from 'model variant specific' to 'not specific'. Demand level is expected to correlate with line-build-rate.</td>
<td>Press components, seals, suspension parts</td>
<td>Model volume sensitive</td>
</tr>
<tr>
<td>Subassembly</td>
<td>Complex assemblies consisting of several components. Different materials are possible within one subassembly. Subassemblies will be produced in several variants (V6, Std, Diesel, etc.)</td>
<td>Headlights, modules, systems in general</td>
<td>Demand pattern is expected to correlate with derivative variant mix</td>
</tr>
<tr>
<td>Options</td>
<td>Parts related to vehicle features that are optional, i.e. generally chosen by the customer. In many cases option parts are constraint items, as e.g. alloy wheels or navigation systems</td>
<td>Air-condition, alloy wheels, satellite navigation</td>
<td>Demand pattern is not expected to correlate with any variable, as demand is entirely driven by option 'take rate'</td>
</tr>
<tr>
<td>Colour coded</td>
<td>Subassemblies, complex and non-complex parts with colour coded features, 'tagging' them to a specifically coloured model</td>
<td>Painted wing mirrors and bumpers, interior trim parts, seats</td>
<td>Sensitive to paint-trim related mix and volumes</td>
</tr>
</tbody>
</table>

Table 1: Component Segmentation

Using the above component categorisation, the survey conducted covers a total of 17 suppliers, three of which are non-specific, five standard, three sub-assembly, three colour-coded, and three option part suppliers. The results of the survey are presented in the next section.

Section 4 presents the findings of the demand and process mapping research and interviews, which provided the background understanding for discussion of the performance indicators as well as the design of the questionnaire survey.
3 Survey Results

3.1 Sample Description

The 17 supplier surveyed split as follows into the five component categories (see table 2):

<table>
<thead>
<tr>
<th>Component Description</th>
<th>Non-specific</th>
<th>Standard</th>
<th>Sub-Assembly</th>
<th>Colour-coded</th>
<th>Option</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Plastic components*</td>
<td>Metal pressings</td>
<td>Fuel tanks</td>
<td>Interior trim parts</td>
<td>Side steps, mudguards, lamp guards</td>
<td></td>
</tr>
<tr>
<td>2. Bedding and wires*</td>
<td>Flywheels, transmissions, suspension arms</td>
<td>Headlamps, rear lamps</td>
<td>Decorative plastic trim (exterior and interior)</td>
<td>HVAC / air condition systems</td>
<td></td>
</tr>
<tr>
<td>3. Petrol engines</td>
<td>Rear axles, front struts</td>
<td>CV joints, drive shafts</td>
<td>Coloured bumpers</td>
<td>Navigation systems</td>
<td></td>
</tr>
<tr>
<td>4. Exhausts**</td>
<td>Sub-frames, metal pressings</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Body-in-white pressings and assemblies</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(*: Mainly Second Tier Supplier, **: more than 25% of Turnover for Aftermarket)

Table 2: Component Segmentation

The majority of the suppliers surveyed belong to companies consisting of up to 5 sites, while other suppliers are part of global ‘mega-suppliers’ with up to 190 production sites. Average group sales turnover is £80m per annum, and the average supplier plant supplies 1.8 assembly plants per customer, although the majority supply one plant only.

The sales turnover per customer varies considerably across the sample as several supplier plants are dedicated to one manufacturer. On average, the main customer accounts for 57.9% of total turnover, yet excluding the three dedicated suppliers, the most important customer accounts for 44.6%. This correlates with Turnbull et al. (1992), who observed that UK suppliers have more clients than their dedicated Japanese counter-parts. In 62% of the 37 analysed supplier-manufacturer relationships the supplier was the single source of supply to the vehicle assembly plant. In particular, subassembly and colour-coded suppliers were found to be single sources, whereas non-specific and standard suppliers mostly were not. This provides validation for the supplier segmentation used.

In terms of involvement in the product development process, 94% of suppliers stated that they are involved, the exceptions being non-specific suppliers. Non-specific suppliers are often not as directly involved in the development process due to the (comparatively) lower complexity of their parts.

The main area of involvement is tooling (81%), followed by product design (60%), and technical product specifications (50%). In 59% of the cases the supplier owns the tooling, although the range covers 33-70%. Tools are more likely to be owned by the vehicle manufacturers for subassembly and colour-coded parts.
All surveyed suppliers were asked to provide data for their four main customers only, which on average accounted for 80.2% of total turnover. The data presented in the following sections hence relates to the four major customers only.

3.2 Supply and Delivery

The total number of parts supplied into the manufacturers averages at 72, with a range from 3 for complex sub-assemblies to 965 for a sequencing operation in a supplier park. The frequency of delivery differs significantly between non-specific and the rest of the sample of 1st tier suppliers. Non-specific suppliers deliver on average every 2.7 days, whereas the rest average every 0.76 days, with no supplier delivering less frequently than once per day. This confirms Turnbull et al. (1993), who found that system and sub-assembly suppliers adopted JIT to a much greater extent than generic component suppliers. Also, suppliers with a majority of Japanese VM customers generally deliver several times per day, although the sample size of 6 does not permit for more indicative analysis. The delivery frequency seems to be primarily driven by two factors - the vehicle manufacturer strategy and the logistics requirements in terms of physical volume, since bulk part suppliers show significantly more frequent deliveries.

The on-time delivery performance quoted ranges between 70 and 100%, and hence distorts the average to a surprisingly poor performance of 97%. Excluding the worst two data-sets, the average rises to just under 99% or a failure rate of 10,100 parts per million, which is still high but within expected levels. In fact, if the vehicle assembly plant sources from 200 supplier with an average delivery reliability of 10,100 ppm, the probability of all 2,000 components for a vehicle being available drops to 13.1%! This phenomenon relates to the basic concept of ‘connectivity’, which states that all events in a system are connected. If one variable changes, at least one parameter in the system changes in reaction. In this sense, short supply of one component will reduce the throughput reliability of the system, as well as potentially altering the demand for other components (‘parallel interaction’, Wilding, 1998).

In terms of who carries out the physical delivery, no vehicle manufacturer collects the parts from their suppliers. Instead 75% of the suppliers are part of a third-party collection on behalf of all or some of their customers, 17% deliver parts using a third-party on their own behalf, leaving 8% use for deliveries. 33% state that their own trucks have some role in delivery. In terms of delivery location, 65% of the suppliers ship into a customer warehouse, 41% deliver to interim warehouses, and only 36% are delivered direct to line-side. Due to several possible delivery schemes for the same customer the responses exceed 100%.

3.3 Demand and Variability

Demand variability has been a frequent point of criticism in the auto sector. Griffiths and Margetts (2000) found that suppliers generally had little confidence in the delivery schedule. The main reasons were identified as poor communication and delays in the system. Although their study only focused on one manufacturer, similar findings have been reported by Turnbull et al. (1992). They found that 44% of suppliers ranked their schedule as substantially variable, yet only 16% as stable. As Callaghan (1984) also concludes, the core reason for demand variability is that it is built into the scheduling system within the vehicle manufacturers, which also is a key conclusion of the Oder Fulfilment Process analysis previously reported.

In his comparison of Japanese and UK auto supply chains, (Hines, 1998) found a ‘golden rule’ that if initial demand variability exceeds 5%, then it will be amplified as it is
passed on in the supply chain. If variability is kept below this threshold, his study suggests that any demand amplification can be avoided.

Harrison (1996) links demand variability to leanness of the supplier, as variability is identified as an obstacle to efficient operational performance. Harrison concludes that suppliers are heavily dependent on the material planning and control systems of the assembler and the resulting quality of demand information provided.

This research focuses on two aspects of demand variability in the supply chain: that between vehicle manufacturer and first tier supplier, and between first tier and second tier suppliers.

**Vehicle Manufacturer – First Tier Supplier**

The first tier suppliers surveyed generally receive three types of information: forecasts, schedules and call-offs largely related to months weeks and days respectively. In some cases, additional information is provided, which generally fulfils similar functions to call-offs. Table 3 outlines the information received in working days, giving the average frequency and time horizons covered. Non-specific suppliers operate on different parameters than other suppliers in terms of forecasts and schedules. Forecasts are received on a six monthly basis and schedules on a 4 monthly basis, both for a period of slightly further ahead than the time between receipt of information. This cannot make for efficient forward planning. For other suppliers, forecasts are generally received monthly for 6 months ahead and schedules weekly for 3 to 12 weeks ahead. Call-offs are basically daily other than for standard components, where the indicated weekly frequency is presumably because less variation is expected. The time horizon of 30 days for call-offs on options presumably reflects the large variation in demand, but it is suspected that VMs cannot be so specific 30 days out or suppliers be capable of working to such detail at such forward notice.

<table>
<thead>
<tr>
<th>[days]</th>
<th>Forecast</th>
<th>Schedule</th>
<th>Call-offs</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Received every</td>
<td>Time Horizon covered</td>
<td>Received every</td>
<td>Time Horizon covered</td>
</tr>
<tr>
<td>Non-specific</td>
<td>186.0</td>
<td>197.5</td>
<td>126.3</td>
<td>139.0</td>
</tr>
<tr>
<td>Standard</td>
<td>11.6</td>
<td>100.6</td>
<td>5.5</td>
<td>17.3</td>
</tr>
<tr>
<td>Sub-Assembly</td>
<td>22.3</td>
<td>196.3</td>
<td>5.0</td>
<td>23.0</td>
</tr>
<tr>
<td>Colour- Coded</td>
<td>22.3</td>
<td>219.0</td>
<td>5.3</td>
<td>33.3</td>
</tr>
<tr>
<td>Option</td>
<td>20.3</td>
<td>167.3</td>
<td>5.0</td>
<td>56.9</td>
</tr>
<tr>
<td>Average over sample</td>
<td>39.1</td>
<td>165.4</td>
<td>27.9</td>
<td>53.9</td>
</tr>
</tbody>
</table>

Table 3: Demand Information Received by Suppliers

In terms of the accuracy of information shown in table 4, it can be seen that the quality of information increases the shorter the horizon and the more frequent the submission, which is to be expected. This fact is also in line with the earlier findings of the vehicle manufacturer scheduling processes, presented in the Order Fulfilment Process report in 2000. Interestingly, non-specific parts are considered to be more accurately forecast despite a much lower frequency of information and although it would be expected that
options are colour coded are the most difficult category to forecast and schedule, standard parts are more inaccurate than them.

<table>
<thead>
<tr>
<th>Variation ['%']</th>
<th>Forecast</th>
<th>Schedule</th>
<th>Call-offs</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Non-specific</td>
<td>1.5</td>
<td>1.5</td>
<td>8.3</td>
<td>1.5</td>
</tr>
<tr>
<td>Standard</td>
<td>15.0</td>
<td>17.4</td>
<td>10.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Sub-Assembly</td>
<td>10.0</td>
<td>10.0</td>
<td>2.8</td>
<td>2.8</td>
</tr>
<tr>
<td>Colour-Coded</td>
<td>10.0</td>
<td>10.0</td>
<td>7.5</td>
<td>7.5</td>
</tr>
<tr>
<td>Option</td>
<td>25.0</td>
<td>25.0</td>
<td>11.7</td>
<td>7.5</td>
</tr>
<tr>
<td>Average over sample</td>
<td>14.9</td>
<td>13.9</td>
<td>7.5</td>
<td>7.1</td>
</tr>
</tbody>
</table>

Table 4: Variation against Actual Requirements

Overall though, the deviation of forecasts and schedules is lower than expected, with an average forecast and schedule error of less than 15% and 7.5% respectively. These findings do not reflect the fact that forecasts were implied to be highly inaccurate in the interviews, and generally over-optimistic. Whilst a slight tendency towards over-estimation can be seen, this general claim of 'unsusable forecasts' could not be verified in the survey. However it should be noted that the survey considered total demand and hence does not reflect particularities of the mix at individual part level, which might be far more problematic for the supplier than the overall volume situation.

In general, the call-offs show very little deviation from actual usage, which again links to earlier findings, as the latter are issued once the actual vehicle build sequence is established and hence should show little variability.

The usefulness of the information for planning, as perceived by the suppliers, reflects this variability pattern. On a scale from 1 (not very useful) to 4 (very useful), forecasts scored 2.5, schedules 2.8, call-offs 3.7, and other types 4.0.

The conclusion reached is that the quality of information is not as large a problem as expected but still a major one in terms of the control needed to operate a 3DayCar efficiently. This, however, neglects to mention one important aspect. In addition to the ‘institutionalised’ information, the vehicle manufacturer also submits informal late amendments, generally via telephone. These changes are particularly disturbing, as they are given at very short notice. A typical case would be a production controller within the assembly plant ringing his counterpart in the supplier and changing the delivery quantity on the day of delivery itself. These late amendments are permitted by 94% of all suppliers, and the average occurrence per week is 3.4 times, with no data-set showing changes less than once per week and a maximum of 7 per week! Unfortunately these late amendments are rarely recorded, hence their impact in terms of volume deviation cannot be evaluated. Nevertheless, it can be concluded that whilst the underlying forecast information shows variability within reason, the suppliers are
subject to frequent late amendments that cause distortion, uncertainty, and lack of co-
ordination across suppliers.

First Tier – Second Tier Link

This section investigates the information passed on by the first tier suppliers to the second tier component and raw materials suppliers. It should be noted that this information is based on 1st tier supplier’s data and could not be cross-validated with 2nd tier suppliers.

In terms of information sent and horizons covered, a very similar picture to the previous section emerges, as shown in table 5. Forecasts are sent twice per month, covering 6 months ahead, schedules are also sent twice a month for a two-month horizon. The main difference appears to be that the call-offs, which tend to be the final orders, are only sent every week or even every other week, covering between one and six weeks ahead. These are for far longer horizons than the vehicle manufacturer call-offs and thus the 2nd tier component supplier is working off much more tenuous and variable data than the 1st tier supplier to determine what they actually build. The reason has to be related to the long order lead-times, to be discussed later in this section.

<table>
<thead>
<tr>
<th></th>
<th>Forecast</th>
<th>Schedule</th>
<th>Call-offs</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sent every</td>
<td>Time horizon covered</td>
<td>Sent every</td>
<td>Time horizon covered</td>
</tr>
<tr>
<td>Non-specific</td>
<td>7.0</td>
<td>60.0</td>
<td>7.0</td>
<td>35.0</td>
</tr>
<tr>
<td>Standard</td>
<td>22.3</td>
<td>207.3</td>
<td>18.5</td>
<td>22.5</td>
</tr>
<tr>
<td>Sub-Assembly</td>
<td>7.0</td>
<td>112.0</td>
<td>14.0</td>
<td>77.2</td>
</tr>
<tr>
<td>Colour- Coded</td>
<td>17.0</td>
<td>134.7</td>
<td>15.0</td>
<td>69.0</td>
</tr>
<tr>
<td>Option</td>
<td>18.5</td>
<td>243.3</td>
<td>7.0</td>
<td>54.0</td>
</tr>
<tr>
<td>Average</td>
<td>16.9</td>
<td>154.7</td>
<td>12.7</td>
<td>55.1</td>
</tr>
</tbody>
</table>

**Table 5: Forecast/Schedule Frequencies/Horizons between 1st and 2nd Tier Suppliers**

The variability of the demand information also shows very similar patterns to the VM-1st tier supplier link. Forecasts and schedules show 10-40% deviations in table 6, although the call-offs show a higher variability, as expected in the context of the longer time horizon and submission frequencies. Interestingly, non-specific suppliers show very low deviations from forecast and options very high deviations, much higher than the VM-1st tier supplier link. The high level of stock in the system must buffer the affects the deviation for the non-specific component suppliers.

---

3 The discrepancy between call-off and schedule horizons at non-specific suppliers, which seems to be reversed, is due to differences in definitions and due to the fact that not all non-specific suppliers send out call-offs in addition to schedules.
The forecast variability increases from non-specific to option components steadily, which reinforces the assumption that the sensitivity towards variability increases in the same manner, i.e. option parts are most sensitive (market, model, derivative and option take rate) and therefore show the greatest variability.

The data also suggests that the variability experienced by first tier suppliers is passed on without significant amplification or distortion to their second tier suppliers, other than options. This conclusion partly confirms the findings of Hines (1998) that demand variability at such low levels does not lead to distortion and amplification in the supply chain.

3.4 Production and Inventory

In order to assess the lead-time and performance of the production systems within the 1st tier suppliers, this section discusses batch sizes and run times, setup times and inventory levels.

- **Batch sizes** largely determine throughput lead-times, inventory levels and the responsiveness to changes in volume and product mix. Sako et al. (1994) found that UK suppliers produced in 2 day batches, although the mapping exercises did show significant differences between batches in assembly and either preceding machining or sub-component production. Unfortunately, the 3DayCar survey did not reveal conclusive data. The information on average batch sizes was either not provided or inconclusive. Furthermore, the diversity of parts within and across suppliers does not permit for meaningful analysis. Thus the analysis here will rely on the process mapping data of 5 component suppliers, which shows batch sizes varying between 3 and 20 days in component production, and of less than 1 day in assembly.

- **The setup times** quoted for the different production stages ranged from 5 to 90 minutes, averaging 29 minutes in assembly and 33 minutes for machining. Although these figures certainly leave room for significant improvement, the setup times in isolation do not seem to pose a serious operational constraint.

- **Inventory levels** within a production system have been frequently used as a key performance indicator for production systems (e.g. Andersen Consulting, 1993, 1994), and can be directly linked to overall lead-times, following Little’s Law.
(Bicheno, 2000). Finished goods inventory has also been linked to variability because it is used to buffer changing demand (Turnbull et al., 1993; Griffiths and Margetts, 2000). The analysis of inventory level is shown in Table 7. As not all suppliers use bought-out components or have assembly stages, the total inventory levels are not the sum of the sub-category averages, but are averaged across all respondents.

<table>
<thead>
<tr>
<th>[days]</th>
<th>Raw Material</th>
<th>Bought-out Components</th>
<th>In-house built Components</th>
<th>Pre-Assembly WIP</th>
<th>Assembly WIP</th>
<th>Finished Goods</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-specific</td>
<td>23.0</td>
<td>60.0</td>
<td>30.0</td>
<td>15.8</td>
<td>N/a</td>
<td>13.8</td>
<td>57.5</td>
</tr>
<tr>
<td>Standard</td>
<td>2.5</td>
<td>4.0</td>
<td>1.5</td>
<td>2.6</td>
<td>1.6</td>
<td>1.2</td>
<td>7.6</td>
</tr>
<tr>
<td>Subassembly</td>
<td>15.8</td>
<td>9.7</td>
<td>7.3</td>
<td>2.5</td>
<td>0.8</td>
<td>1.1</td>
<td>14.8</td>
</tr>
<tr>
<td>Colour-coded</td>
<td>25.0</td>
<td>12.5</td>
<td>N/a</td>
<td>12.5</td>
<td>1.5</td>
<td>7.7</td>
<td>33.7</td>
</tr>
<tr>
<td>Option</td>
<td>10.7</td>
<td>13.5</td>
<td>2.0</td>
<td>2.2</td>
<td>3.3</td>
<td>4.0</td>
<td>19.4</td>
</tr>
<tr>
<td>Average over sample</td>
<td>13.1</td>
<td>11.6</td>
<td>5.7</td>
<td>6.2</td>
<td>1.9</td>
<td>4.5</td>
<td>21.9</td>
</tr>
</tbody>
</table>

Table 7: Inventory Levels within First Tier Suppliers

A very interesting picture emerges within an overall average total inventory of 21.9 days, the majority being held in raw materials and bought-in components, as well as a high level of finished goods. Within the sample, significant differences exist between the component categories, with the highest stocks in the non-specific category. The main reason is the high material and bought-out component stock which also affects the colour-coded category. The underlying processes here are generally batch-driven, such as injection moulding or wire drawing, and use raw materials supplied by process manufacturers. They tend to deliver materials only in large quantities. The lowest stock levels were found within standard part and subassembly suppliers, where the low levels of finished or semi-finished products indicate a close coupling to the actual requirements. Overall, the high levels of finished products are an indication of them acting as a buffer function, as described by Turnbull et al. This explains why the non-specific component supply chain is seen to have the least variation in forecast to actual and standard components the most other than options, which are indeed difficult to forecast. The use of Vendor Managed Inventory (VMI) or consignment stock on the other hand was surprisingly high, as six suppliers claim to use some form of VMI with one or more customers. However, the data does not show a correlation of stock levels and supplier using VMI.

### 3.5 Capacity and Volume Flexibility

Volume flexibility has also been highlighted as a factor influencing the flexibility and responsiveness of a system (Slack, 1991). However, this research points out that the direct causal relationship between spare capacity and response capabilities has to be questioned. Nevertheless, as the availability of component production capacity is a potential enabler for the overall system responsiveness, this section investigates to what extent capacity is currently used, and to what extent this capacity could be increased. Table 8 shows the current average utilisation in terms of actual running time against the total manned capacity. This means the total machine time that labour is theoretically available for production given the maximum utilisation of these resources. The additional capacity availability can thus be discussed at two levels. First, capacity can be increased by reducing downtime and hence increasing the average utilisation.
Second, the capacity can be increased by providing more labour for longer production hours, thus increasing the manned capacity. The total theoretical additional capacity is a combination of both – using a similar logic as that proposed by Nakajima (1988) in describing Overall Equipment Effectiveness.

On average, production processes or machines are being used 82.4% of their manned time. Taking the maximum utilisation of 84.3%, and the actual production hours worked per week into account, on average 58.4% of the capacity is effectively used over a seven day week. In other words, suppliers theoretically have an average 41.6% capacity available (min 24.6% to max 49.8%) if production hours were extended to the maximum of 24 hours for 7 days a week. However, it only takes one supplier to have insufficient capacity to make it impossible to build a finished vehicle, hence it is the one supplier with the least flexible resources that determines the overall scope for capacity increases.

<table>
<thead>
<tr>
<th>[%]</th>
<th>Average Capacity Utilisation</th>
<th>Maximum Machine Capacity Utilisation</th>
<th>Production Hours 7/24</th>
<th>Effective 7/24 Capacity Utilisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-specific</td>
<td>81.3</td>
<td>83.3</td>
<td>90.5</td>
<td>75.4</td>
</tr>
<tr>
<td>Standard</td>
<td>75.9</td>
<td>80.3</td>
<td>62.5</td>
<td>50.2</td>
</tr>
<tr>
<td>Subassembly</td>
<td>82.5</td>
<td>82.5</td>
<td>72.3</td>
<td>59.6</td>
</tr>
<tr>
<td>Colour-coded</td>
<td>86.3</td>
<td>88.3</td>
<td>70.8</td>
<td>62.5</td>
</tr>
<tr>
<td>Option</td>
<td>84.6</td>
<td>95.0</td>
<td>56.0</td>
<td>53.2</td>
</tr>
<tr>
<td>Average over sample</td>
<td>82.4</td>
<td>84.3</td>
<td>69.3</td>
<td>58.4</td>
</tr>
</tbody>
</table>

Table 8: Current Capacity Utilisation of Suppliers

More interesting than the potential overall increase in capacity is the volume flexibility in response to changes in demand. Table 9 describes the suppliers percentage ability to increase their capacity in relation to the given timeframes.

<table>
<thead>
<tr>
<th>[%]</th>
<th>Capacity Increase one Month out</th>
<th>Capacity Increase one Week out</th>
<th>Capacity Increase one Day out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-specific*</td>
<td>N/a*</td>
<td>N/a*</td>
<td>N/a*</td>
</tr>
<tr>
<td>Standard</td>
<td>29.7</td>
<td>14.0</td>
<td>6.9</td>
</tr>
<tr>
<td>Subassembly</td>
<td>42.2</td>
<td>30.0</td>
<td>15.0</td>
</tr>
<tr>
<td>Colour-coded</td>
<td>46.7</td>
<td>41.1</td>
<td>11.7</td>
</tr>
<tr>
<td>Option</td>
<td>52.1</td>
<td>22.1</td>
<td>4.6</td>
</tr>
<tr>
<td>Average over sample</td>
<td>40.4</td>
<td>22.3</td>
<td>6.7</td>
</tr>
</tbody>
</table>

(*: Inconsistent Responses)

Table 9: Suppliers’ Ability to increase Capacity
A very significant increase in overall capacity averaging 40.4% can be achieved with one month’s notice. At shorter notice, the data suggests that it is possible to increase capacity by 22.3% within a week, and 6.7% within a day’s notice. Overall, the data suggests that suppliers have a high volume flexibility, well above the deviations from forecast. This suggests the flexibility is sufficient to cater for a 3DayCar process and that stock could be removed from the current process by using capacity in a more flexible way. However, as the data presented is concerned with the total capacity, it is likely that at part number level this capacity flexibility might not be achieved. Particular resources are likely to pose a capacity bottleneck and limit the increase in throughput (Goldratt, 1990), or be constrained or affected by other parts made by a different supplier. This has been described as ‘parallel interaction’ (Wilding, 1997). Hence it is the least flexible supplier, not the average one, who will determine the limit of the additional flexibility in the supply chain.

Suppliers indicated in interviews that feasible capacity increase would rely on overtime and extra shifts, since there is a key constraint to additional manning due to the lack of qualified labour and the ‘inflexibility’ of being able to reduce/increase the workforce at short notice. Additional capacity levels are thus not sustainable over a long period. It was also stated that in many cases the changes in volume are far less of a problem than changes in the product mix that are frequently demanded by the vehicle manufacturers. This statement has to be seen in relation to the set-up times discussed earlier, which revealed inconclusive data as to the potential constraints due to this factor. This and other operational constraints were further investigated with suppliers and the results are shown in the following section.

### 3.6 Operational Constraints

In order to get a comprehensive picture of operational constraints, the respondents were asked to rank seven factors across three main areas – facility, labour and supply – in terms of their impact on the operation. In addition, two empty fields were provided in order to suggest further constraints that were not listed. The quality of information from the manufacturers was deliberately not mentioned in order to check whether it actually was perceived as a main constraint, as suggested in the interviews. Table 10 outlines the results.

<table>
<thead>
<tr>
<th>(0=no constraint, 3=strong constraint)</th>
<th>Facility</th>
<th>Labour</th>
<th>Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Change-over</td>
<td>Batch Sizes</td>
<td>Flexibility</td>
</tr>
<tr>
<td>Non-specific</td>
<td>1.5</td>
<td>1.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Standard</td>
<td>0.3</td>
<td>0.7</td>
<td>0.5</td>
</tr>
<tr>
<td>Subassembly</td>
<td>1.5</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Colour-coded</td>
<td>0.7</td>
<td>0.3</td>
<td>0.7</td>
</tr>
<tr>
<td>Option</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Average over sample</td>
<td>0.9</td>
<td>0.7</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Table 10: Flexibility Constraints

As can be seen, no clear picture emerged identifying one or more explicit factors as inhibiting the suppliers’ operations. On the contrary, the data strongly suggests that
individual suppliers face very specific problems related to their particular circumstance. This is also reflected in the additional factors mentioned, which included the supply of tooling, labour absence rates, machine downtime, and production quality. Very interestingly, the quality of the demand signal was not mentioned. Therefore the conclusion has to be reached that although demand variability is a problem to suppliers, other factors also impact on their flexibility, such as labour, facility and supplier related issues. These factors will vary across suppliers, with no consistent picture emerging. Whilst facility and labour/capacity issues have already been investigated, the following section will further elaborate on the link with the second tier suppliers, as this was (marginally) the most important area highlighted in table 10.

3.7 Raw Material and Component Supply

On average, the 1st tier suppliers analysed in this survey use 142 bought-out parts, with the exception of one supplier who uses 250,000 bought-out parts in their operation. As expected, the number of main raw material types is lower at 3.5 on average, ranging between 1 and 5. These main types or categories of raw material however are sourced from a wide range of suppliers. Table 11 shows the total number of second tier suppliers used, split into bought-out components and raw materials. Again, as not all suppliers purchase both categories, the total number of suppliers per category is not the sum of the number of supplier types.

<table>
<thead>
<tr>
<th>[n]</th>
<th>Component Supplier</th>
<th>Raw Material Supplier</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-specific</td>
<td>30.0</td>
<td>7.0</td>
<td>16.8</td>
</tr>
<tr>
<td>Standard</td>
<td>12.8</td>
<td>46.0</td>
<td>25.3</td>
</tr>
<tr>
<td>Subassembly</td>
<td>13.7</td>
<td>46.8</td>
<td>71.0</td>
</tr>
<tr>
<td>Colour-coded</td>
<td>26.8</td>
<td>66.8</td>
<td>25.7</td>
</tr>
<tr>
<td>Option</td>
<td>27.5</td>
<td>35.2</td>
<td>106.0</td>
</tr>
<tr>
<td>Average over sample</td>
<td>20.3</td>
<td>42.5</td>
<td>45.7</td>
</tr>
</tbody>
</table>

Table 11: Number of Second Tier Suppliers

First tier suppliers have to deal with a considerable degree of complexity in terms of purchasing and inbound logistics, with an average of 45.7 suppliers per plant in total, or 20.3 component and 42.5 raw material suppliers as applicable.

In order to quantify further the link between the tiers in the supply chain, table 12 shows the average order lead-times from 2nd tier suppliers, the delivery frequencies and delivery performance in terms of on-time delivery.
<table>
<thead>
<tr>
<th></th>
<th>Order Lead-time Raw Materials [days]</th>
<th>Order Lead-time Components [days]</th>
<th>No of Deliveries per Day (Raw Mat and Components)</th>
<th>On-time Delivery (Raw Mat and Components) [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-specific</td>
<td>7.0</td>
<td>30.0</td>
<td>1.5</td>
<td>96.7%</td>
</tr>
<tr>
<td>Standard</td>
<td>46.0</td>
<td>12.8</td>
<td>0.6</td>
<td>98.4%</td>
</tr>
<tr>
<td>Subassembly</td>
<td>46.8</td>
<td>13.7</td>
<td>0.6</td>
<td>87.1%</td>
</tr>
<tr>
<td>Colour-coded</td>
<td>66.8</td>
<td>26.8</td>
<td>0.5</td>
<td>99.1%</td>
</tr>
<tr>
<td>Option</td>
<td>35.2</td>
<td>27.5</td>
<td>0.2</td>
<td>96.8%</td>
</tr>
<tr>
<td><strong>Average sample over sample</strong></td>
<td><strong>42.5</strong></td>
<td><strong>20.3</strong></td>
<td><strong>0.7</strong></td>
<td><strong>95.6%</strong></td>
</tr>
</tbody>
</table>

Table 12: Second Tier Supplier Order and Delivery Performance

The order lead-times average at 42.5 and 20.3 days for raw materials and components, respectively, which indicates low flexibility on behalf of the second tier suppliers, and can also be linked to the high raw materials and component stock levels found within the first tier. In particular, certain raw material suppliers show a high degree of inflexibility, which has previously been criticised as a root cause for supply chain inefficiencies (Hines et al., 2000). The lead-time for raw materials at non-specific suppliers only relates to one data-set and therefore needs to be questioned, as it might rather relate to call-off lead-times within existing orders from these suppliers than actual order lead-times.

Whilst the ordering shows long lead-times, the actual deliveries are frequent. In fact the average delivery is made almost every day, and no less frequently than once a week. The on-time delivery performance is a concern, however, and was also mentioned as one of the strongest inhibitors in the overall operational constraints, as discussed above.

This could well be due to the distance between first tier and second tier suppliers being very high. On average across all raw material and component suppliers, the distance is 1,783 miles and also shows a high deviation (σ=3,795) – which undoubtedly has to be seen in the light of the trend towards global sourcing.
3.8 Inhibitors to Flexible Supply

To investigate the impacts of unresponsive second tier supply further, the respondents were asked to rank the factors according to their perception of the level of constraints they pose (see table 13).

<table>
<thead>
<tr>
<th>Factor</th>
<th>Distance to 2nd Tier Supplier</th>
<th>2nd Tier Order Lead-time</th>
<th>1st Tier Plant Capacity</th>
<th>Low Delivery Frequency / Low Volumes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-specific</td>
<td>2.0</td>
<td>1.7</td>
<td>1.7</td>
<td>1.0</td>
</tr>
<tr>
<td>Standard</td>
<td>1.3</td>
<td>1.7</td>
<td>1.3</td>
<td>1.7</td>
</tr>
<tr>
<td>Subassembly</td>
<td>1.5</td>
<td>1.0</td>
<td>1.0</td>
<td>0.5</td>
</tr>
<tr>
<td>Colour-coded</td>
<td>0.7</td>
<td>1.0</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Option</td>
<td>2.0</td>
<td>2.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td><strong>Average over sample</strong></td>
<td><strong>1.4</strong></td>
<td><strong>1.4</strong></td>
<td><strong>1.1</strong></td>
<td><strong>0.9</strong></td>
</tr>
</tbody>
</table>

Table 13: Inhibitors of Flexibility within First Tier Suppliers

The results indicate that distance and order lead-time are the major constraints to flexible supply and the supply link between two tiers in the system.

4 Demand and Process Mapping

Process maps have been used within three case studies of different types of component suppliers to investigate the information and production processes operating in the motor industry in detail and draw some conclusions on which areas cause inefficiencies or flexibility restrictions and hence inhibitors of a 3DayCar.

4.1 Headlight Supplier

This supplier produces head and rear lights for several major European vehicle manufacturers. The process map shows the information and material flows for a headlight supplied to a Japanese manufacturer in the UK. On average, 600 headlamps (300 pairs) in 5 basic variations (10 different headlights in total) are produced, in addition to which after-market parts are supplied on a daily basis into a warehouse on-site at the manufacturer site, 45 miles away.

Demand from the manufacturer is received every week via an Odette EDI system, giving 3 weeks firm orders split into daily requirements.

The manufacturing process is controlled by an MRP system, which is connected electronically through an EDI system with the vehicle manufacturer. The MRP system issues weekly work schedules for the sub-component production and issues the orders to raw material and bought-out component suppliers. For the particular part, the main components are made in-house, 27 bought-out components and 10 raw materials are purchased from their 85 second tier and 15 raw material suppliers (for the total site).

The main steps in manufacturing include injection moulding of the frame, housing, lens and reflector, lacquering and plating of the inner frame and reflector. The lens moulding and lacquering are located in a separate clean-room since the process is sensitive to dust and dirt and has high scrap rates of up to 10%.

Figure 3 shows the process map, which is disguised for confidentiality reasons.
Several key learning points can be identified. Most importantly, the overall order fulfilment process within the supplier operates at two levels, which are de-coupled or separated by significant inventory.

Whilst the assembly cells, which are very flexible and have less than 10 minutes change-over time, can produce to exact daily requirements, the preceding processes operate on weekly schedules issued by the MRP system. In between, several days of inventory de-couple the steps, despite having significant finished goods inventory to the customer side as buffer against variability. This layout was also found in several other suppliers, particularly where a sub-component production step is feeding into an assembly or paint and assembly step. In the case of a metal pressing supplier, the de-coupling inventory averaged 1-2 weeks, since the batch sizes through the presses were up to 4 weeks of demand.

In this sub-assembly supplier case, interviews with the production manager revealed that the finished component inventory was held as buffer against production, not demand uncertainty. The main concern was the plating and lens moulding process. Also, he admitted that the single-piece capability in the assembly area was not fully exploited, pointing out that the supplier did not have any say over the delivery scheme into the assembly plant. More frequent deliveries, maybe even line-side, and tighter coupling into the vehicle build sequence were not 'issues ever mentioned or demanded' by their customer. As a consequence, there are three stocking locations between the component and vehicle assembly, if one includes the line-side stock in the plant.

The sub-component production is a typical MRP-driven batch production process. Interestingly, the MRP system runs every Thursday, although the new schedule from the customer is only available on Friday morning. Therefore, the information is delayed for 5 production days before it is used! Once the MRP system has run, it issues weekly schedules to all sub-component production steps. These schedules are then manually altered or ‘smoothed’ by the supervisors, according to their needs. The resulting unsynchronised production seems a main driver for the substantial inventories, as well as change-over times of 0.5 to 4 hours. Table 14 shows the average inventory held on site, and the planning and ordering lead-times.

<table>
<thead>
<tr>
<th>Process Stage</th>
<th>Inventory Level</th>
<th>Planning or Ordering Lead-time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finished Products</td>
<td>2 days</td>
<td>Daily shipping schedule</td>
</tr>
<tr>
<td>Assembly WIP</td>
<td>Hours</td>
<td>Daily shipping schedule</td>
</tr>
<tr>
<td>Bought-out Components*</td>
<td>A-parts: 5 days</td>
<td>Weekly order</td>
</tr>
<tr>
<td></td>
<td>B-parts: 15 days</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C-parts: 30 days</td>
<td></td>
</tr>
<tr>
<td>In-house Built Components</td>
<td>1-2 days, 5-10 days for small parts</td>
<td>Weekly MRP schedule, manually altered</td>
</tr>
<tr>
<td>Component Production WIP</td>
<td>3-5 days</td>
<td>N/a</td>
</tr>
<tr>
<td>Raw Materials</td>
<td>40 days</td>
<td>5 weeks fixed orders, weekly delivery</td>
</tr>
</tbody>
</table>

*using the ABC classification in terms of value times volume, e.g. (Schonberger and Knod, 1997)

Table 14: Inventory Levels, Planning and Ordering Lead-times
In conclusion, this case shows to what extent component and sub-component production within first tier suppliers is de-coupled from the actual demand signal of the vehicle build schedule, although the vehicle manufacturer provides three weeks of relatively stable demand (5% variation on high-volume items). This de-coupling effect is subsequently the demand passed on to second tier and raw material suppliers. The reasons for this de-coupling of demand are the multiple inventories along the process, as well as a batch-driven planning system at the supplier and associated long set-up times that 'justify' these batches. To what extent quality issues actually disturb the process could not be evaluated, although the high scrap rates of certain processes suggest that this issue is further contributing to the need for safety buffers.

Planning systems and the resulting demand and supply dynamics will be further explored in section 7.5.3.

4.2 Powertrain Supplier – Engine Plant

In terms of vehicle components, the engine plays a special role. In terms of value, the engine accounts for up to 20% of the total componentry cost and is generally the single most valuable component. Despite its value, which in itself justifies further analysis, several other issues suggested that an investigation of the engine supply was a crucial element in new vehicle supply systems.

First, the engine is a high-complexity component, consisting in a fully dressed state of c.350 parts. Furthermore, the engines are specifically customised for certain markets and vehicles, although the basic engine design is standard. The reasons are different emission standards and fuel types across the markets. This applies to as much to less developed countries, where leaded fuels are still being used, as to Europe. In Germany, for example, the lowest-grade fuel is 91° octane, whereas in the UK 95° octane is the least grade available. As a consequence, in many cases fuel handling, ignition and various smaller parts have to be adjusted. In this case study, 20-36 main derivatives are being produced. Consequently, both engine and vehicle assembly are capital-intensive, high-complexity assembly operations in direct sequence. This poses significant management challenges. In fact, engine supply and availability were mentioned as major concerns in terms of constraints for the scheduling process in the interviews at the vehicle manufacturers.

Secondly, engine plants are rarely located next to the assembly plants they are feeding, which causes logistics delays and further potential sources of supply uncertainty. Due to the high-capital investment needed, most manufacturers single-source engines from specialised engine plants on a regional or global basis. A plant typically only produces 1-4 different types of engines, yet the average vehicle model takes 3-8 different engine types. In Ellesmere Port, 2.5 V6 Ecotec’s are built for GM world-wide, yet the Astra which is assembled on the same site does not take the engine at all. Ford Europe sources engines from centralised engine plants in Bridgend, Dagenham and Valencia, plus the V6 Duratec from the USA. Honda in Swindon is one of the few examples where the majority of engines are built in sequence with the vehicles on the track. Yet even in Honda’s case diesel engines are sourced from Rover, and high-performance petrol engines from Japan. In most other cases, engine build is not synchronised with vehicle build: a serious logistics issue.

The process mapping analysis was therefore critical in identifying potential inhibitors or sources of uncertainty for the overall vehicle supply system.
The Generic Process

The engine plant is located in central Europe and builds 500,000 petrol engines per annum. Three main types of engines are built, two of which are low-specification high-volume, and one is a high-spec low volume engine. All engines are supplied into more than two assembly plants across Europe. Major components are sourced from a total of 500 suppliers, including the castings, but the main components are typically machined before assembly. The demand information from the vehicle manufacturer’s central scheduling department is received through the standard supplier scheduling system, providing weekly firm schedules. These schedules are used to determine the daily shipping requirements, which are made up from a buffer stock of finished engines of 1-1.5 days. The stock is also used to buffer variability caused by production downtime and engine failures in the hot test (3.3% reject rate). The actual production control and scheduling of engine assembly is de-coupled from this daily shipment schedule, as the weekly plans are manually smoothed and batched into standard lot sizes (48 in this case compared to a 800-900 daily shipment requirement). This altered weekly plan, which is subject to frequent, informal daily adjustments is given to the shop-floor foreman and team-leaders for execution. It is also re-entered into the same standard supplier scheduling system to determine the parts requirements for the engine plant. Suppliers to the engine plant receive one month’s firm orders on a volume basis, plus weekly plans and daily firm call-offs at a more detailed level. High-volume suppliers deliver 2-3 times daily and inbound stock levels range from 0.4 – 3 days.

The physical flow is very simple as the engine plant is basically a series of highly-automated machining lines for heads, blocks, cranks, con-rods and camshafts, all of which feed the assembly line through an interim buffer holding 1.5-2.5 days of stock. The assembly line lead-time is only 5 hours, yet considerable changeover times of 16-18 hours have to be accommodated in the engine plant if the line is switched over from one engine type to another.

The assembly line fully assembles and dresses the engines, using a further 300 bought-out components, which account for 62% of the total component value of the engine. After assembly, the engines are hot-tested for 3 minutes, before they are ready for despatch via rail and truck. Following the longest lead-time component and excluding rework, the actual production lead-time for machining, assembly and testing accounts for just under 24 hours, far less than originally expected. Figure 4 shows the generic process map for a high-volume engine.
Engine Plant
Big Picture Map of the Order Fulfilment Process -
Version 1.0
M Holweg

Suppliers
500 Production
Suppliers
15k to
2x1.2 V, 3 per family

Teams

Material Planning and Logistics
Weekly Planning and Logistics
Daily call-off

Engineering
Engineering
Manager

Production
Production
Programming

Supplier Scheduling System
Supplier Scheduling System

Available Capacity

Forecast ahead of engine requirements

Run weekly
6 to 8 x per
1 month

3.3% Failure
4 to 6 days

Assembly & Dressing
Cylinders
5 hrs throughput, c/o 16-18 hours

Cylinder Block Assembly
Cylinder Head Assembly

Cylinder Block Machining
Cylinder Head Machining

Crankshaft Machining
Cylinders

Cylinder Head Assembly 900-1,200 per Train
Cylinder Block 1,200 per Train
Crankshaft 700 per Train

300 parts bought-out, 62% of value

Blocks: 0.4 days
Sparkplugs: 3 days
Fuel Rails: 3 days

1 - 1.5 days FGI used to smooth out variability

PLANTS

HQ
800-900/day
400 per Train
500 per Truck
120 / truck

Weekly Plan, Daily Firm
Runs weekly

Daily Review and Adjustments to daily plan depending on backlog, etc.

Daily call-off
6 months f/c
1 month firm

Production Pre-Planning
6m F/C
1m Firm

Daily Build and Work Report

Figure 4: Order Fulfilment Process – Engine Plant
Build Consistency Analysis

As the process mapping analysis did not reveal any structural inhibitors, further analysis was undertaken of the actual build compared to the original build schedule. This is defined as ‘build consistency’ or ‘schedule adherence’ and was quoted as 75% by the production control department. To investigate this figure further, the build consistency in terms of planned daily versus actual build was analysed for the three main engines for a period of three months, starting in January 2000.

Engine A is low-volume, high-spec, B and C are high-volume standard spec. Each of these engines is supplied into more than one assembly plant, and is being installed in several models across two brands.

The graphs in figures 5, 6, and 7 show the daily schedule, the actual build, and the daily and cumulative deviation of planned versus actual build for the three different engines.

![Engine Build Consistency - Type A](image)

As can be seen, the engine build schedule for type A is very stable. The actual build shows a certain degree of variability which is buffered by a consistent attempt to build ahead of schedule. The cumulative deviation is therefore contained to a maximum of 70 units below schedule, which equals 0.33 days of average requirements and is covered by the finished goods inventory.
In the case of engine type B, as shown in figure 6, the daily schedule requirements show reduced levels for January, yet are stepped up to a stable level from February onwards. The actual build however shows serious shortfalls despite attempts to recover by overbuilding. The cumulative deviations reach c.1 days requirements given an average demand of 1,400 units per day, hence reinforcing the ‘need’ for the finished engine buffer after testing.
Again, the type C engine build schedule shows very predictable patterns with a slight increase after the first month (see figure 7). The actual build again shows serious shortfalls, and the cumulative deviation exceeds the 1.5 days safety buffer on various occasions.

The build consistency across the three examples analysed shows significant variability, which is partially covered by a buffer of finished products. Case C is, however, likely to introduce short term supply uncertainty into the system, as well as affecting the vehicle manufacturer build schedules because of the lack of parts. The engine plant production control manager claimed that no short deliveries have been made to the assembly plants, yet this statement could not be verified or disproved.

The reasons for variability are mainly shortages and quality defects related to 2nd tier suppliers or machining operations, although a certain degree of hot-test failures are due to quality defects in assembly.

Overall, the analysis shows that a considerable degree of uncertainty is caused by the variability in engine build, despite the de-coupling via the buffer of finished engine stocks.

The next section will present an analysis of how the component demand of the vehicle manufacturer is transferred into the first and second tiers of the supply chain.

### 4.3 Electronic Navigation System – Demand and Supply Dynamics Example

As pointed out in both the literature and the interviews, demand variability and its impact on the supply chain are a serious concern in the auto component industry. This section aims to provide further evidence by analysing how the vehicle manufacturer demand is transformed as it passes from the vehicle manufacturer into production schedules within a first tier supplier, and subsequently into material and component requirements for the second tier supplier.

The example will use data collected at a major European electronics supplier who supplies most European vehicle manufacturers with navigation systems and radios. The product chosen is a navigation system for a luxury vehicle that has an option take rate of 95%. Therefore, the actual demand pattern is largely stable since the requirements closely match a vehicle assembly line rate of 196 cars per day.

The analysis was conducted as an additional exercise during a 3-day process mapping workshop. The information flow within the company is driven by an MRP system, which is directly linked to the vehicle manufacturer. The schedules however are manually overridden and adjusted according to an internal forecast. The resulting schedules are given to the line managers in charge of assembly and integrated-circuit-board (ICB) lines and the plastic moulding shop, who manually adjust these plans to their requirements.

The material flow shows in-house integrated circuit board production lines and in-house plastic component production both feeding into dedicated assembly and testing lines. Assembly also involves a considerable number of bought-out parts sourced from second tier suppliers, which also include high-value ICB’s. The main parts in a navigation system are the mainboard, the tuner ICB, the GPS module, the drives, and the front (including the screen).

The analysis covers three months (June – early September 2000), and monitored demand requirement from the vehicle manufacturer, the supplier assembly of systems, and the demand and supply patterns for components of these systems. All components considered in this analysis are only used in this product, hence the demand patterns are directly comparable.

Figure 8 shows demand for the finished product by the vehicle manufacturer, the internally generated schedules for the in-house ICB and plastic front cap, and the orders sent out to the second tier supplier for the ICB.
The fairly stable call-offs from the manufacturer which range between 144 and 192 units per day\(^4\), are highly amplified as they are translated into internal schedules for sub-components and external bought-out components.

The schedules for the in-house ICB are completely erratic with lot sizes between 458 and 2,758 units within irregular schedule intervals. The schedules for the plastic cap show even worse amplification, with call-off lot sizes of more than 4,000 units on two occasions! The reason for this distortion could not be explicitly identified during the visit, yet inaccurate master data files and badly maintained lot-sizing data were quoted as root causes. The discussion during the presentation of the findings further revealed that the distortion in the demand signal was a known fact to the production line manager, and also a main reason why manual planning was necessary in addition to the MRP schedules. Interestingly, the demand signal passed on to the 2\(^{nd}\) tier supplier does not show further or similar distortions from the MRP schedule. A fairly regular ordering pattern of 1,000 or 2,000 units occurs in practise, although at irregular intervals. This is due to the fact that one member of the purchasing staff has the task of manually smoothing supplier orders and converting them into reasonably standard ordering sizes. Therefore, the actual demand passed on to the next tier shows less erratic patterns, yet still bears little resemblance to the original demand of the vehicle manufacturer, which ranges between 144 and 192 units per day. (This artificial ‘filtering’ or smoothing of distortion has also been described by Hines (1998)).

In terms of the actual production, it can be seen in figure 9 that despite the highly amplified orders, the actual production levels for final assembly and plastic cap production are far less amplified. Although a significant distortion can be observed, the average plastic cap production runs cover 1 to 3 days requirements.

\(^4\) The outlier with 350 is due to a misaligned holiday pattern, but does not reflect variable demand
In summary, figure 10 shows how the stable call-off pattern from the vehicle manufacturer converts into a highly distorted and amplified demand pattern within one tier of the supply chain. The MRP system used in this case is working out of control, forcing both production and purchasing staff to manually override the system outputs. Overall, the demand amplification is 1:22 in the worst case internally, 1:10 externally to the second tier supplier, yet is contained to 1:8 within the navigation system factory (plastic cap production).
As a result of this major deficiency in the planning system, high inventories are kept in the system. Between the end of the assembly line at the supplier and the point of utilisation at the vehicle manufacturer itself, 8 days of stock are held in testing and in the two in-transit warehouses. In terms of component stock, 1.1 months are held on average at this supplier.

A subsequent interview with the purchasing director did reveal further evidence for the need of Purchasing’s involvement in the supplier scheduling, as well as showing that certain stock levels of components are required due to long replenishment lead-times from suppliers. It was claimed that the first tier electronics suppliers in the car industry are a very small buyer group compared to telecommunications, and hence face difficulties in obtaining constrained items. In the case of this supplier, several integrated circuits or ‘chips’ were made specifically for them by Asian suppliers, who would only build in large batches due to the set-up times involved. The availability of electronic components was quoted as the single most critical operational constraint that also affects their 2nd tier suppliers.

5 Conclusion & Recommendations

5.1 Conclusion

The research has revealed several factors that inhibit the flexibility of first tier component suppliers and hence their ability to respond to changing requirements from vehicle manufacturers.

- The ability to adjust delivery frequency is severely restricted since the vehicle manufacturer generally dictates it in line with their reception requirements & constraints at the plant.

- While suppliers in general can increase capacity by over 40% at volume level, the problem is at mix level both in terms of capacity and variation. This is due to long set-up times and large batch sizes. Particularly in the machining and sub-component production stage, where batch sizes of up to one month were found. All suppliers in the process mapping were using an MRP system for the planning of these production stages. This is an additional contributory factor to large batch sizes.

- Increased capacity levels are not sustainable in the longer term due to a lack of qualified labour.

This inability to cope with changes due to inflexible production scheduling and batching is subsequently reflected in the inventory levels. In total, an first tier component suppliers carry an average 21.9 days of inventory. The majority of this inventory consists of materials, yet an average 4.5 days of finished products were held. This exceeds the expectation derived from Griffiths and Margetts (2000), who state that UK suppliers achieve flexibility through two days worth of consignment stock held at the buffer store. The primary function of this inventory is most certainly to buffer against the inability to respond to the variability in demand.

This relationship between finished goods inventory and delivery frequency has been confirmed, since the more closely integrated sub-assembly and standard part suppliers showed far less WIP and finished component inventory. The raw material and component inventories, however, showed high levels throughout, with very few exceptions. The need for these buffers arises from the long order lead-times and the distance between the first tier and its second tier suppliers. Also, the first tier suppliers have to cope with a considerable amount of complexity in terms of overall parts and materials purchased and the number of suppliers involved.

- The actual forecast and schedule variability of the vehicle manufacturers’ requirements was highlighted as a major concern and inhibitor in the interviews, yet was not verified as an inhibitor to responsiveness. On the other hand, late amendments were very
frequently issued by the vehicle manufacturers, which explains both the lack of confidence in the demand information and to some extent the finished goods inventory levels. In that sense it is not the ‘poor communications in the UK supply base’, which have been identified as a problem (Sako et al., 1994), but the last minute changes by the manufacturer – a fact previously pointed out by Hines (1998).

The same variability experienced at first tier level is passed on to the second tier in the supply chain. While the sample was too small to be rigorous, the demand and supply mapping example of the electronics suppliers revealed a tenfold amplification of the signal.

The inhibitors to responsiveness with first tier suppliers can be grouped into internal and external factors. Internally, the reliability of processes and the long setup and batch times reduce the supplier’s flexibility. This is compensated to a large extent by inventory rather than flexibility in production. Externally, the late amendments by the customers are a root cause for uncertainty as well as the long order lead-times and distances to the second tier suppliers, which again are buffered by inventory.

Overall, no consistent picture identifying one or several key inhibitors to responsive component supply has been established and no conclusion beyond generic observations can be reached. In order to determine supplier capability for supporting a build-to-order approach at system level, a component-by-component analysis will be necessary, taking the different individual settings into account. This is also the conclusion of Griffiths and Margetts (2000).

5.2 Recommendations

These findings have wide-ranging implications for the component supply sub-system and raise several questions. First, will the requirements derived from a more responsive vehicle supply system result in further component inventory in the supply chain. The initial results of the 3DayCar simulation indicate an increased inventory requirement of 9% in order to support a responsive build-to-order model (Simons et al., 2000). However, the model assumes current batch sizes and lead-times within the suppliers. Hence the second question that needs to be addressed in future research is to what extent this extra requirement for stock can be mitigated through better demand information, closer synchronisation of vehicle build and component production beyond assembly, and small-lot component production. Indications from the simulation show that passing information in real time to suppliers alone, will, in fact, enable a reduction in current stock levels.

Second, the findings highlight the necessity to align decisions on component sourcing and stocking with the overall system goal of providing the enabling responsive order fulfilment. An initial conceptual model has been developed, as shown in figure 11, based on the initial five component categories discussed and the findings of the process mapping and interviews. The categories have been chosen to reflect the degree of customisation and value of the components, as well as considering the special case of powertrains. The original option and colour-coded categories can be either standard components, sub-assemblies, systems or modules, and have been subsumed in these categories in order to keep the model as simple as possible at this stage.
The model shows how stocking points (shown here as inventory triangles) need to be positioned in relation to the response time or assembly sequence horizon. This is defined by the time that the actual sequence of vehicles is decided before vehicle build is commenced on the assembly track. Components that can be planned, produced, and delivered within this response time can be built in sequence with the vehicle build on the assembly track. The longer this horizon, the more suppliers can be integrated into a sequenced supply scheme and reduce the need for inventory. The 3DayCar has a response time of 36 hours. The stocking points mark the de-coupling points in the system, which by definition hold inventory in order to buffer the variation between forecast-driven and demand-driven parts in the supply chain (Mason-Jones and Towill, 1999).

- **Modules and systems**, which are highly customised and high-value parts, need to be assembled in sequence, since holding inventory is generally cost prohibitive. Therefore, these suppliers will have to locate their final assembly operations within the vehicle assembly sequence horizon in order to minimise delivery time. This has driven the current move towards the establishment of supplier parks around vehicle assembly plants.

- For **Standard components**, there are two basic options. First, these suppliers can also locate at least their final production or assembly (if any) operations so as to fall within the vehicle assembly sequence horizon in order to provide sequenced supply. Second, where co-location is economically infeasible, the restructuring of such suppliers into modular and system supplier or second tier suppliers (which have also been referred to as ‘0.5-tier suppliers’ in the automotive press) is an alternative option. This is a current development within the general movement to modular assembly (Cousins, 1999).
For **sub-assemblies**, the same principles as for the first two categories apply. Within this category however, vehicle-specific and labour-intensive components such as wiring-harnesses are often quoted in interviews with vehicle manufacturers as particular problems. Current wiring harnesses are highly labour-intensive and hence often sourced from low-wage countries, such as North-Africa or Eastern Europe, which involves obvious logistics lead-times. These delays however, which can account for up to 6 weeks, pose a serious limitation for the flexibility of the overall system, as any vehicle build is bound to the pre-specified harness schedule. Therefore, the alternatives are either to re-locate the entire harness operation, to late configure harnesses close to the assembly plant, build standardised harnesses that can cope with a wide range of vehicle specifications, or seek a technical solution (such as multiplexing for example) to overcome the flexibility constraints.

**Powertrains**, i.e. engines and transmissions, not only represent a very significant proportion of the overall vehicle cost, but due to the centralisation of engine plants also pose a potential risk to the overall system flexibility. In theory, co-locating the engine plants and make the engines in sequence should be the objective. In practical terms however, co-locating engine and assembly plants is infeasible under current technological conditions, hence the focus needs to be variety elimination through standardisation and the provision of frequent deliveries in order to minimise the resulting scheduling constraints for the vehicle build.

For **non-specific** components, which are generally low-value and non-customised parts, sequenced build or re-location are most likely uneconomical, and hence a de-coupling point in the form of an inventory buffer is the only alternative. Part value, supplier distance, and logistics arrangements will determine the size of the buffer.

In conclusion, the model shows that component supply for responsive build-to-order vehicle supply systems has to be governed by two basic concepts:

1. **Move complexity close to the order penetration point**
2. **Place configuration points within the order fulfilment time horizon**

Ad 1. The more complex and the further away input (in form of components) is away from the core order fulfilment process, the more it will pose a systemic inhibitor to responsiveness. Therefore, global sourcing has to be put into serious doubt with regards to responsive build-to-order, in particular where high-value or highly customised items are sourced.

Ad 2. The configuration point is the point in time where the decision on the final specification of the components is made. This applies to colour and features and the decision will generally be made within the component manufacturer. In order not to impose any delays into the order fulfilment process (and without holding additional stock) this configuration point needs to be within the time horizon dictated by the assembly sequence. This assembly sequence horizon is derived from the customer requirements and the overall system capability of responding to customer demand. In the case of the 3DayCar, this horizon reduces to 36 hours!

Whilst providing a good initial understanding, the model can only outline a conceptual solution to the general implications for the sourcing and stocking decision of components within a responsive vehicle supply system. A dynamic analysis at individual component level is required based on comprehensive actual data in order to produce meaningful results. Further research is required in conjunction with an actual implementation case.
5.3 General Comments

In addition to the specific conclusions, the underlying study reinforces a range of other proposals made as part of the 3DayCar research. These include;

- **Real-time information sharing** across the supply chain, in order to minimise uncertainty and reduce the ‘demand amplification’ or ‘bullwhip’ effect, which is largely driven by uncertainty, delay, batch-driven ordering and production, as well as inventory (Forrester, 1958; Lee et al., 1997).

- **As few amendments of the sequence as possible** should be made after the sequence has been set, as this could introduce uncertainty and trigger dynamic distortion in the supply chain – which ultimately result in excess inventory.

- **Inbound logistics should be integrated** between vehicle manufacturer, component supplier, and logistics, so that delivery planning on shorter lead-time that takes into account requirements of all three parties.

- **Inventory in the supply chain should be visible**, and duplication of safety buffers should be avoided. A strategy to achieve this is to introduce consignment stock, Vendor-Managed Inventory (VMI), or Pay-on-Production (POP).

These general comments aim both at supporting the 3DayCar objectives as well as providing a stable dynamic behaviour of the supply chain. Any kind of change to the component supply chain should bear in mind that

- **Uncertainty** of information and material supply,

- **Delay**, both on information and material flow level (e.g. batch order processing or physical inventory), and any

- **Decision points** (where the information and material flows are altered, e.g. through forecasting, batching, or multiple planning)

will have an adverse effect on the dynamics of the supply chain.
References


Appendix – Definitions

- **Component**: a component is a discrete proportion of a vehicle, which has standard interface with the wider vehicle system. A component is the basic unit within a vehicle, and comprises of one or more distinct parts, which can be made of one or different materials.

- **Component segment**: within the range of components in a vehicle, these can be grouped in several categories according to their value (A,B,C parts), materials (steel, plastic, electronics, etc.), complexity (standard, derivative specific, optional), and functionality (e.g. drivetrain, suspension, body parts, interior, etc.). Segmentation of components helps to make judgements about the entire component volume without investigating every individual part.

- **Module**: a module is a pre-assembled, significant proportion of the vehicle, which comprises of a range of components. As opposed to systems, modules generally cover physical or dimensional aspect of the vehicle, such as the ‘front-end’ (radiator, bumper, lights) or cockpits (incl. Instrument panels, heating unit, dashboard). Module are generally pre-assembled in-sequence and close to the vehicle assembly plant and are specific or customised for individual vehicles.

- **Part**: a part is a single portion of a vehicle, which is generally made of a single material and does not comprise of an assembly of sub-units. A typical vehicle is built of c.15,000 parts, which are pre-assembled into 2,000-4,000 components before being delivered into the vehicle assembly plant.

- **Subassembly**: a subassembly is a component, which is built of a significant number of individual components. Manufacturing a subassembly involves an assembly operation within the component supplier, whereas components not necessarily have to pass through an assembly step before being delivered. A subassembly generally is not customised the same degree as modules or systems, but could also be vehicle-specific. Subassemblies can also be integrated into a wider system or module.

- **System**: similar to modules, a system is a large subassembly of a range of components. In contrast to modules, systems represent one functional dimension of a vehicle. This could be a brake system, which covers all brake pipes and the main cylinder, or the fuel handling system from fuel tank, fuel pipes and pump up to the injector units in the block.

It should be noted that systems and modules are often used in very similar or confusing contexts in the automotive press due to the lack of a generic definition.