The Order Fulfilment Process in the Automotive Industry
Conclusions of the Current State Analysis

by
Matthias Holweg
Lean Enterprise Research Centre
Cardiff Business School

Ref: S1 – 7/00
July 2000
## INDEX

1 INTRODUCTION

1.1 OUTLINE ........................................................................................................................................ 5
1.2 OBJECTIVE AND RESEARCH QUESTIONS .................................................................................. 6
1.3 SCOPE & DELIMITATION ................................................................................................................ 6

2 RESEARCH APPROACH

2.1 THE RESEARCH MODEL .................................................................................................................. 7
2.2 THE BIG PICTURE MAPPING TOOL .............................................................................................. 8

3 ORDER FULFILMENT LOOPS

3.1 INTRODUCTION ............................................................................................................................. 9
3.2 THE 5 ORDER FULFILMENT LOOPS ............................................................................................ 9
3.3 SALES SOURCING .......................................................................................................................... 11
3.4 THE RISK PROFILES ..................................................................................................................... 12
3.5 CONCLUSION .................................................................................................................................. 13

4 CURRENT STATE – ORDER FULFILMENT PROCESS

4.1 SYSTEM CAPABILITY DEFINITION ............................................................................................... 14
4.2 THE SUBSYSTEMS ........................................................................................................................ 15
4.3 SUMMARY - GENERIC MODEL ...................................................................................................... 27
4.4 DEMONSTRATED BEST PRACTICE ............................................................................................... 29
4.5 CONCLUSION .................................................................................................................................. 29

5 PRODUCT VARIETY & COMPLEXITY

5.1 INTRODUCTION ............................................................................................................................. 32
5.2 PRODUCT VARIETY ....................................................................................................................... 32
5.3 DEMAND – SPECIFICATION PARETO ......................................................................................... 34
5.4 COMPLEXITY .................................................................................................................................. 35

6 OTD TIME COMPRESSION – CONCEPTS AND APPROACHES

6.1 INTRODUCTION ............................................................................................................................. 38
6.2 ‘KANBAN SUPERMARKET’ ............................................................................................................ 38
6.3 OPEN ORDER PIPELINE & ORDER AMENDMENT ..................................................................... 38
6.4 CONTINUOUS IMPROVEMENT ..................................................................................................... 39
6.5 LATE CONFIGURATION AND POSTPONEMENT ............................................................................ 39

7 CONCLUSION

7.1 CURRENT SUPPLY SYSTEMS ........................................................................................................ 41
7.2 THE 4 PRINCIPLES OF A ‘BUILD-TO-ORDER’ SYSTEM .............................................................. 43
7.3 THE 5 FUTURE CHALLENGES FOR THE AUTO INDUSTRY ....................................................... 44
7.4 FUTURE RESEARCH ....................................................................................................................... 45

APPENDIX A: LITERATURE REVIEW – RESPONSIVE ORDER FULFILMENT

INTRODUCTION ............................................................................................................................. 46
SYSTEM DYNAMICS ...................................................................................................................... 46
TIME COMPRESSION ...................................................................................................................... 46
AGILE MANUFACTURING .............................................................................................................. 46
THE LEAN APPROACH .................................................................................................................. 47
DE-COUPLING / DECISION POINT ANALYSIS .......................................................... 48
P:D RATIO ....................................................................................................................................... 49
MASS CUSTOMISATION ............................................................................................................... 50
PRODUCT VARIETY AND COMPLEXITY ..................................................................................... 51
SYNTHESIS ..................................................................................................................................... 51

APPENDIX B – ABBREVIATIONS ........................................................................................................ 52

REFERENCES ................................................................................................................................... 53
Executive Summary

This report sums up the major findings of the Current State Analysis of the order fulfilment process in the automotive industry, and concluded that:

- Current vehicle scheduling and supply systems are mainly driven by the sales forecast, not by actual market demand for order build. Only 30% (over 3DayCar sample, UK 1999) of the vehicles were built-to-customer order, with 12% of these being adjustment to stock orders already existent in the manufacturer order bank.

- OTD system capability is on average 40.1 days, with 85% of the time delays occurring in the order processing, scheduling and sequencing subsystems.

- The Demonstrated Best Practice, evaluated over the 3DayCar sample, shows a system capability of 10.6 days. Considering that this already falls outside the expectations of 13% of UK customers in terms of order-to-delivery for a custom built vehicle, it was concluded that a build-to-order system will only be feasible by introducing a new logic of scheduling systems, and not by reengineering or improving existing systems.

- As current vehicle supply systems are unable to provide custom-built vehicles within the expected timeframe of the customer, manufacturers effectively are forced to rely on vehicle stock in the market place. Alternatively, manufacturers might face the risk of losing sales, as customers might buy a different brand with better availability.

- Redesigned systems are necessary if vehicle manufacturers are to embrace the philosophy of providing custom-built vehicles from the factory within an acceptable timeframe for all customers. Piecemeal improvement, as sometimes promoted as the way ahead, is simply futile, as the whole concept behind it is based on ‘push’ or wholesale supply systems, which also has left its legacy in the IT systems that have grown ‘organically’ alongside over the years.

- Manufacturing itself was found to offer little potential for time compression, yet the unreliable body, paint, and assembly sequences compromise lean distribution and ultimately lengthen the logistics lead times. Alternative order tagging or de-coupling points can be used however to cut down lead times and give greater reliability to order sequence. An intermediate solution might be to use a resequencing approach after the paint shop to restore an original sequence, if the technical complexity allows for it.

- Complexity is a general problem, both in product variety and technical complexity. The two most important factors identified are:
  - The total number of specification permutations offered in the marketplace, which determine a vehicle manufacturer’s ability to source certain vehicles from stock and is a major factor in the efficiency of line balancing activities and component stock control.
  - The number of body-in-white variations and colours sprayed, which determine the flexibility and potential sequence reliability within the manufacturing process.

The less complexity these two factors show, the greater the manufacturer’s ability to move towards a flexible production system and ultimately towards a build-to-order strategy.

- IT system complexity and batch processing were identified as further problems, introducing a minimum of 4-5 overnight updates for an order to go through the system. Also, the current system architecture inhibits change and improvement.
While this report has concluded that a 3DayCar is not achievable with current scheduling procedures, production processes, and information systems, it is believed that solutions can be found and that new technology is available to make a 3DayCar achievable within the next 10 years. The challenge is to prove that demand, complexity and systems can be cost effectively managed, together with the necessary changes in organisation, measures, costing systems and organisational mindsets and cultures.

Future research on the logistics and component suppliers, the simulation, and the organisation and finance streams will aim to consolidate this view.
1 Introduction

1.1 Outline

This report details the findings of the current state analysis of the order fulfilment process for the six manufacturer sponsor companies, which was conducted as part of the Systems Stream’s research within 3DayCar from March 1999 to March 2000. The findings will be presented in a generic form for confidentiality reasons and hence compromises on company specific details. This report therefore should be seen as complementary to the individual research reports produced for each relevant sponsor, which describe the particular order fulfilment process for each company.

As the subject discussed is highly complex, this report will focus on major findings only, in order to ensure readability - if at any one stage more detail is required, please do not hesitate to contact the author directly.

In terms of outline, the report will comprise the following areas:

- **Introduction**, defining research objectives, scope and limitations of the study
- **Research approach**, describing briefly the theoretical underpinnings of the research
- **Order Fulfilment Loops**, discussing the different ways of fulfilling customer orders in the car industry
- **Research Findings** relating to
  - A **Current State Analysis** of the order fulfilment process, showing both a generic and a demonstrated best practice map
  - **Product Variety and Complexity**
  - Current **approaches to time compression** taken by the vehicle manufacturers (VMs)
- **Conclusions**, summing up the findings and concluding with a set of requirements for a ‘build-to-order’ system

Additionally, there are Appendices that feature further information and references and a brief literature review on time compression, the order fulfilment process in general and related concepts.
1.2 Objective and Research Questions

The objectives of this research were to investigate the current system’s ability to respond to customer demand and to draw a high-level ‘map’ of the order fulfilment process, together with a high-level benchmark in terms of ‘system capability’.

The research questions in detail are:

1. How capable are current vehicle supply systems in terms of order fulfilment lead times for custom built vehicles, and what approaches and concepts are used to shorten these lead times?

2. What is the product variety and complexity, and to what extent do these factors influence the order fulfilment system?

3. Concluding from the above questions – what general principles would a future state vehicle supply system have to adopt in order to be capable of providing custom-built vehicles in minimal order-to-delivery times?

1.3 Scope & Delimitation

This study focused mainly on the sponsoring Vehicle Manufacturers (VM) of the 3DayCar programme, analysing the order fulfilment process for one at least one major volume model being produced in a European assembly plant for each sponsor. However, additional comparative research at other VMs was undertaken and will be pointed out as appropriate.

Supply and distribution chain related issues will not be commented on as yet, since they are the subject of the ‘3DayCar Supply Chain Study’ and the ‘3DayCar Logistics Study’ in the second and third year of the programme.

The assumption is that the sample size of plants and processes analysed is representative of the industry as a whole. This assumption is backed up by the fact that all vehicle manufacturers analysed use a central standard planning and scheduling approach, which applies to all European plants and models. Therefore, the material flow part of the ‘big picture maps’ shows plant-related detail, whereas the information flow shows the process generally standard to all operations.

Due to the complexity and dynamic of product, process and settings in the car industry certain simplifications had to be made to keep the study feasible and to allow for comparative analyses. These simplifications will be pointed out as appropriate.

This study was conducted between March 1999 and May 2000, and the data in general represents the current state as found at the point of the research. The order fulfilment process data was collected between May and September 1999, and the product variety data relates to the specifications offered in the UK market in 1999.
2 Research Approach

2.1 The Research Model

To assess the ability for responsive order fulfilment in the automotive sector posed serious difficulties in terms of complexity and available resources to conduct the research. Additionally, no models are discussed in the literature in terms of how this responsiveness could be assessed. The models available, e.g. Fisher (1997), were found to be too unspecific and were of a qualitative nature, and hence did not allow for comparative benchmarking. Therefore they had to be rejected. Instead, a new model was created and pioneered within 3DayCar (Holweg & Hines, 2000), taking a systems perspective to the research problems described below.

The research itself is based on a multi-method approach, although the model mainly relies on high level process mapping. This was then verified and triangulated with a series of semi-structured interviews. In addition, secondary sources such as company performance data, product and sales documentation were used.

The research model used is derived from the systems theory approach. It is based on a standard input-output model, as shown below.

The basic principle behind this system approach is to reduce complex processes to basic inputs and outputs, which then can be analysed. In this context the order fulfilment process is seen as a simple system, with inputs (e.g. customer demand, customer expectations), and outputs (e.g. delivery times to customer). The system, which has to react to the various inputs, consists of several subsystems, all of which work together to form the total system. These subsystems are order-scheduling, production, vehicle distribution, etc, each with their own characteristics (=system parameters) in terms of lead times, frequencies and production batches.

The ‘order fulfilment strategy’ box refers to the way the system is set to operate. In this case it refers to the general approach to order fulfilment, i.e. products are made to forecast (MTF) and supplied from stock or products are made or assembled to order (MTO / ATO), etc.

Splitting complex processes up into inputs, outputs and subsystems permits:

- **comparison of performance of the overall system** in relation to inputs and outputs
- **demonstration of the interaction** of the different subsystems
• comparison of the performance of the different subsystems where a common subsystem structure can be identified (i.e. subsystems perform the same function, as for example the different production scheduling systems.)

The key variables considered in this analysis are:

• Customer waiting tolerance towards the order-to-delivery (OTD) time
• Throughput lead time and delays in the particular subsystems and the overall system
• Product variety, in relation to the range of specification choices offered to the customer in the market place
• Sales sourcing data, in terms of what percentage of sales is made from distribution centre stock, or satisfied via factory orders.
• Delivery probability over time, on the basis of how long does it take for 10% of orders to be fulfilled, for 20%, etc.

2.2 The ‘Big Picture Mapping’ Tool

The tool used to investigate and visualise the order fulfilment process follows the ‘Big Picture Mapping (BPM)’ methodology approach proposed by Rother and Shook (1998) to map internal value streams. In this case, it is used to visualise complex processes and their information and material flows. The application of this technique to analyse the capability of the order fulfilment process was originally not intended by Rother and Shook, who used the tool for value stream and shop-floor improvement, but was suggested in a similar manner by Shapiro et al (1992).

In brief, the objectives of the ‘Big Picture Mapping’ are to gather data quickly (low interference) and to be able to show complex processes in one diagram. The sources of information are interviews and company performance data, apart from the actual workshop or group discussion. In summary, BPM is a tool that allows one to understand and model complex processes in a short period and in a standardised format. The standardised format furthermore allows a common approach for comparison of dealers, suppliers, vehicle manufacturers and logistics providers.
However, BPMs can only represent the standard process and might have to compromise on particular detail, which is the reason why it should not be used as a stand-alone tool, and should be backed by other research – like semi-structured interviews and secondary data, as in this case.

3 Order Fulfilment Loops

3.1 Introduction

This chapter reviews the basic objectives of the order fulfilment strategies, describes the 5 basic order fulfilment loops relevant to the automotive industry, and evaluates these in terms of their specific cost and risk profiles.

The general objective of any order fulfilment process is to supply the customer with a product of the right specification within an acceptable timeframe. In this context, ‘build-to-order’ seems an obvious approach for the auto industry - to have a demand-driven production system which aims to provide custom-built vehicles in a minimal lead time – given the product variety offered to customers and the value of the finished product.

One would imagine that the car industry, no longer enjoying the luxury of having demand exceeding its ability to supply, would be governed by these objectives anyway. Whilst the huge scale of investment needed to deliver a product to the market at an economically competitive price creates certain constraints, providing the customer with a car that meets his exact requirements as quickly as possible, has unmistakable logic.

If companies could provide custom built vehicles to order, as opposed to make them to forecast, it could solve the major deficiencies of the current system:

- **Redundant stocks** would not occur, as cars would only be manufactured to customer order, relieving manufacturers and dealers of the stock financing burden - and the airfields full of cars would disappear.
- **Cars** would be sold without **additional discounts** due to inefficient distribution, as there is no need to grant discounts for alternative specification or to clear old stock - hence allowing for reasonable margins for both manufacturers and dealers.
- **Customer satisfaction** would rise, as right specification and acceptable lead time are the major objectives of the Order-To-Delivery system.

However, despite this obvious logic, concerns are uttered, particularly from the manufacturers, as to whether a ‘build-to-order’ system can replace the current ‘make-to-forecast’ or order amendment system. To discuss the potential pitfalls of the ‘build-to-order’ system, a closer examination of what the order fulfilment process means is needed.

3.2 The 5 Order Fulfilment ‘Loops’

Although simplistically, often only the make-to-stock and build-to-order scenarios are discussed, there are in fact five different types of order fulfilment, or ways in which new cars can be supplied to customers, as shown below in Table 2.

In this context, it should be noted that the term ‘build-to-order’ is generally applied to vehicles supplied against both loop 4, whereby forecast orders in the pipeline are amended to customer requirements and loop 5. While this is true, loop 4 needs to be seen critically, as it still bears the danger of being a sophisticated ‘push-based’ supply system, i.e. if no customers arrive, the forecast orders (that have been decided weeks or months ahead) are built and pushed into the market place. Hence, the percentage of orders actually amended to real customer requirements could be claimed as ‘built-to-order’, but the remainder of orders might still be still pushed.
<table>
<thead>
<tr>
<th>Loop</th>
<th>Order-to-Delivery Approach</th>
<th>Description</th>
<th>Order-to-Delivery Time (UK data)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loop 1</td>
<td>Dealer Stock</td>
<td>The car is bought from the stock at the visited dealer. (17%)*</td>
<td>Instantly available</td>
</tr>
<tr>
<td>Loop 2</td>
<td>Dealer Transfer</td>
<td>The car is located at another dealer in the country, and transported to the dealer. The additional cost occurring is in the region of £100 to £130 for a dealer 'swap' within the UK. (13%)*</td>
<td>3 days</td>
</tr>
<tr>
<td>Loop 3</td>
<td>Distribution Centre (DC)</td>
<td>The vehicle is sourced from a central stock location, controlled by the manufacturer. Generally the dealer does not hold any new cars in his own stock, so most sales would be made from the DC itself. (39%)*</td>
<td>4-7 days</td>
</tr>
<tr>
<td>Loop 4</td>
<td>Order Amendment</td>
<td>Orders are laid out in line with forecast in the first place, and once the customer specifies his order, these unsold ‘pipeline’ orders are amended to customer requirements. In advanced systems, an open order pipeline exists which allows a dealer to access all unsold other dealer orders in the market to satisfy his customers, whether they need specification amendment or not. (12%)*</td>
<td>Variable, 11 days on average</td>
</tr>
<tr>
<td>Loop 5</td>
<td>Build-to-order</td>
<td>This implies that the order is entered as a new order into the system. This happens only in 18%* of the new vehicle purchases of sponsors at the moment, with an average order-to-delivery lead time of 48 days (Volume Cars)</td>
<td>Average 48-60+ days</td>
</tr>
</tbody>
</table>

* Figures in brackets represent the average sales from each loop source as indicated in Figure 3.
3.3 Sales Sourcing

The following figure shows the sales sourcing, i.e. the distribution of order fulfilment over the 5 loops, as found in the 3DayCar sample in 1999. It can be seen that the major loop source is distribution centres but the minimum and maximum for each loop indicates many different supply system practices between the UK sponsor manufacturers.

![UK Sales Sourcing 1999](image)

Figure 3: Sales Sourcing (average not sales weighted)

It should be noted here that due to the 5 different ways of fulfilling an order in the car industry, a variety of different order types can be found in the systems. Essentially, there are stock orders, customer-specified orders and support orders.

- **Stock orders** refer to orders placed without a real customer requirement, but according to forecast sales requirements. Specifications generally are ‘frequent runners’, and commonly these vehicles will be sold from stock (Loop 1-3), or will be amended to customer specification while in the pipeline. Stock orders can be raised by dealers, national sales companies (NSC) or the vehicle manufacturers themselves.

- **Customer-specified orders** are generally sold orders, which are built to order (Loop 5) or converted stock orders (Loop 4). Specifications are ultimately defined only by the customer.

- **Support orders** are all other orders in the system, as for example dealers’ orders for showroom cars and demonstrators, or vehicle manufacturers’ orders for their own company-car fleet, etc. Also, pre-production orders, vehicle test and exhibition orders are raised by the manufacturer.

Production in general sees most of these as ‘production orders’, and in most cases the plants are not able to distinguish between sold / customer orders, and stock orders. The plant will however have visibility of show cars and pre-production vehicles, as special quality and assembly rules apply.
3.4 The Risk Profiles

Each of these approaches, or loops, comes along with different advantages and risks, as shown in Table 3. For loops 1 to 3, and obvious risk of redundant stock is present, as the vehicles may come obsolete at model year change or when the model runs out, necessitating very significant discounts for disposal. Also, a ‘specification risk’ occurs, as those cars in stock might not be the right specification for the customer. Potential stock redundancy and wrong specification then relate to the overall risk that discounting might have to be used to sell those cars.

A potential risk of lost sales occurs if the Order-to-Delivery time exceeds the customer’s waiting tolerance. The customer not willing to wait might instead buy from a different brand offering shorter Order-to-Delivery times. This risk is called ‘lead time risk’ or ‘lost sales risk’.

Also, as the provision of vehicle production capacity is one of the major costs incurred, manufacturers tend to strive for the most efficient utilisation of their production and assembly facilities. And this is where the ‘build-to-order’ is most often criticised. Manufacturers fear for their efficiency of their plants, as ‘real’ customer orders might not arrive in a sequence that most suits the production schedules of the plants. Producing vehicle to forecast and selling from stock therefore provides a possible alternative to under-utilising the factories or even losing the customer.

However, there seems to be some misunderstanding: in the long run, ‘build-to-order’ has on long term same capacity utilisation risk as a forecast driven production system – if there is no demand, there is no justification for build in either system. ‘Build-to-order’ is as sensitive to pricing and incentivising as ‘make-to-forecast’, with the simple difference that in the ‘build-to-order’ scenario the production volume would need to be supported before the vehicles are built - as opposed to supporting clearing of existing stock from the airfields after the vehicles are built. The actual risk of ‘build-to-order’ is short-term volatility, i.e. if no orders come in the first week of the month, but all arrive in the second week.

This fear is justified, as under the current reactive management there is no way of catering for short-term volatility. However, the flaw is not to be seen in the ‘build-to-order’ approach, but in the manufacturers' ability to manage demand. Car makers these days do not understand and manage their demand, but simply react to stock build-ups and, in the last resort, to incoming order levels. They also increase marketing efforts if the market share target seems under threat, as this measure is still perceived as a key indicator of business success. (This approach is clearly driven by the ‘volume-push’ mentality or ‘more is better’, neglecting any customer- and profit related measures. It is for example not measured, what profit contribution each vehicle sold achieves. The point of performance measurement and costing structures will be a key project of the future work within the Organisation stream of 3DayCar, hence will not be discussed in further detail here.)

In contrast, a ‘build-to-order’ system would require a proactive management of demand and a segmentation of demand. Non-urgent orders, such as demonstrator and showroom cars for dealerships, the cars for use of the own employee and even large fleet orders – which generally provide visibility for several weeks ahead – could be used to buffer the service for those customers who require short delivery times on their custom-built vehicle. A buffer of those orders would then enable the manufacturer to overcome short-term fluctuations.
### Table 2: Risk Profiles of Order Fulfilment Loops

<table>
<thead>
<tr>
<th>Order Fulfilment Loop</th>
<th>Stock Redundancy Risk</th>
<th>Alternative Specification Risk</th>
<th>Discounting Risk</th>
<th>Lead Time Risk</th>
<th>Capacity Utilisation Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Dealer Stock</td>
<td>++++</td>
<td>++++</td>
<td>++++</td>
<td>0</td>
<td>++</td>
</tr>
<tr>
<td>2 Dealer transfer</td>
<td>+++</td>
<td>+++</td>
<td>+++</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>3 Distribution centre</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>4 Order amendment</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>5 Build-to-order</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>++++</td>
<td>++++</td>
</tr>
</tbody>
</table>

[0: No risk, +: Low risk, ++: Moderate risk, +++: High risk, ++++: Very high risk]

### 3.5 Conclusion

The ‘build-to-order’ approach clearly shows superior risk structures in the distribution area, however the risks in terms of lead time and capacity utilisation need to be addressed.

These risks need to be countered by reengineering the scheduling and supply system towards greater responsiveness, i.e. shorter OTD lead times, to be able to supply vehicles within the customers' waiting tolerance.

Additionally, greater production flexibility, coupled with demand management and real time information flows respectively, will be required to avoid idle production capacity.

Hence the central question that need to be addressed is whether current vehicle supply systems are capable of providing short enough lead times and sufficient flexibility to support ‘build-to-order’?
4 Current State – Order Fulfilment Process

4.1 System Capability Definition

This chapter feeds back the results of the actual order fulfilment process analysis and the subsequent benchmarking and system capability analysis.

The central research question in this section is to define how capable the current vehicle supply systems are. **System capability refers to the minimal (system-related) throughput time for a custom-built vehicle.** Hence system capability figures will differ significantly from the average lead times for factory orders, as these orders’ lead times are affected by capacity queues, rework and other delays in the process. The system capability analysis assumes that all subsystems are running at **optimal** throughput, no rework or other delays occur. It therefore gives a benchmark only on the system’s basic ability to support a build-to-order scenario, and does not judge on current average performance, which primarily depend on the demand-supply situation for that particular model (i.e. the throughput times for a model in high demand are longer than for a model where supply exceeds demand, etc.).

The following sections will briefly describe the different subsystems involved in the order fulfilment process, which is highlighted in the Figure below.

![Order Fulfilment System Diagram](image-url)
4.2 The Subsystems

4.2.1 Sales Forecasting

The underlying sales forecasting process is essentially a demand forecast-gathering process between the VM sales department, the national sales companies (NSC) and the dealers, and serves as input for the production programming.

In general, the dealers are asked to supply their annual volume forecast 1-4 months before the end of the year, which will then be revised by the NSC on a monthly or bi-monthly basis.

Although the forecast process does not directly interfere with the order fulfilment process, there are certain influencing factors being determined in the sales forecasting-programming-allocation loop: Volume commitment, which can either rest with the dealer or the NSC. Where the volume commitment rests with the dealer, there are cases of the dealer being forced to supply orders in line with his sales forecast volume up to 90 days ahead of production on a model-engine-derivative basis! The reason for committing the dealer to sales volume is to perpetuate a wholesale driven ‘push’ system, which unsurprisingly operates a high level of sales from stock with the probability of high discounts.

Alternatively, the commitment for volume can rest with the NSC, which commonly also holds central stock (non-dealer allocated) in regional or national distribution centres.

The following table shows the correlation between volume commitment and the degree of sales from dealer stock, including transfers.

<table>
<thead>
<tr>
<th></th>
<th>Volume Commitment rests with...</th>
<th>VM operates in UK</th>
<th>Stock Orders raised by Dealers?</th>
<th>% Sales from Dealer Stock and Transfers</th>
</tr>
</thead>
<tbody>
<tr>
<td>VM A</td>
<td>Dealer</td>
<td>RDCs</td>
<td>Yes</td>
<td>62</td>
</tr>
<tr>
<td>VM B</td>
<td>NSC</td>
<td>RDCs</td>
<td>No</td>
<td>12</td>
</tr>
<tr>
<td>VM C</td>
<td>NSC</td>
<td>RDCs</td>
<td>No</td>
<td>18</td>
</tr>
<tr>
<td>VM D</td>
<td>Dealer</td>
<td>RDCs</td>
<td>Yes</td>
<td>28</td>
</tr>
<tr>
<td>VM E</td>
<td>NSC</td>
<td>DC</td>
<td>Yes</td>
<td>40</td>
</tr>
<tr>
<td>VM F</td>
<td>NSC</td>
<td>DC</td>
<td>Yes</td>
<td>21</td>
</tr>
</tbody>
</table>

Table 3: Volume Commitment v Sales from Dealer Stock
As the table shows, a correlation between the volume commitment being at the dealer level and the percentage of sales from dealer stock can be seen, although the sample size used is not statistically significant. Nevertheless, if the dealer sells from his stock, there is a high probability of additional discounts being given.

### 4.2.2 Production Programming

![Production Programming Process Diagram]

The production programming meeting makes the initial decision on the production volumes, which is essentially a compromise between netting-off of the available production capacity and the ‘sales request’ for production, from each market, taking into account forward sales and stock level requirements.

As a result of the programming meeting, the boundaries for the production are set for the next period. There is also a financial input, as it is essential to define a profitable programme (because of the differential return per vehicle for low and high-spec cars).

Production programming meetings are held generally on a monthly basis (exceptionally bi-monthly), and typically determine the production programme for the next 3 months.

<table>
<thead>
<tr>
<th></th>
<th>Programming held every</th>
<th>Takes effect in</th>
</tr>
</thead>
<tbody>
<tr>
<td>VM A</td>
<td>Month</td>
<td>M+3</td>
</tr>
<tr>
<td>VM B</td>
<td>Month</td>
<td>M+2</td>
</tr>
<tr>
<td>VM C</td>
<td>Month</td>
<td>M+3</td>
</tr>
<tr>
<td>VM D</td>
<td>2 months</td>
<td>M+3</td>
</tr>
<tr>
<td>VM E</td>
<td>Month</td>
<td>M+3</td>
</tr>
<tr>
<td>VM F</td>
<td>Month</td>
<td>M+3</td>
</tr>
</tbody>
</table>

*Table 4: Programming Frequencies*

As a result of the programming meeting, production volumes, long-term shift patterns, and the volume allocations of models and derivatives are decided for the different markets. In some cases, other constraint items, e.g. high-demand engines, are allocated between markets.

The intention is that the programme will be fixed up to the month where the changes take effect, but will in reality be subject to amendments up to M-1 due to fall-down in achievement or new constraints occurring.
4.2.3 Order Entry

Order entry determines the process of the order between being entered into the system at the dealership or via the internet until it finally reaches the order bank and is ‘available for scheduling’. The process in general involves:

- **Order specification** at the dealership/over the internet according to customer requirements. This assumes that the financial clearance for the transaction and other formalities have taken place beforehand.

- **Allocation check** of the order at the NSC in some cases to see whether the dealer and the market have an allocation for the order or not. If not, the order is artificially delayed by the NSC until the next allocation period. This happens regardless of whether other markets actually use their allocation for the model in question, as only very few systems permit allocation swapping or provide the visibility in the system to do so.

- **Feasibility check** of the order to see if the order conforms to the specifications offered for the particular model in the particular market and model-year. These specifications are held in a central table database, which holds all the information on which specifications are standard, and which are offered as options or packages. The check ensures that if the customer orders ABS as an option, although it is standard, the order is rejected and corrected by the dealer. Model year changes cause the most problems here, as the orders might be placed for the old model-year but due to the delays are actually built as the new model year.

- **Bill-of-material (BOM) explosion**, whereby the order is converted from the dealer codes (which define the entities: Model A, 3dr, 161 petrol, red metallic, A/C as option) into a bill of materials for that particular vehicle. Only when the scheduling system knows which parts are needed to build the vehicle, can the order be scheduled and the supplier be issued. Obviously identical orders, placed in two different countries, will have different BOMs, as the country-specific equipment (LHD/RHD, standard equipment, emission level, etc.) alters the parts requirements.

- **Transfer into the order bank**, where the order is held until it is assigned to a build period in a plant and transferred into the production schedule.
In general it may appear that the order entry subsystem works ‘on-line’ or even ‘real-time’, but this is not the case. The orders are entered online, but subsequently will be held up at least overnight to enable the code conversion and the BOM explosion, although the actual allocation and feasibility check lasts only 2 hours in the best performer’s case.

4.2.4 Order Scheduling & Sequencing

Order scheduling and sequencing are the core steps in the order fulfilment process (OFP), as at this stage the incoming demand is converted into production orders. Hence, the scheduling tool defines the throughput lead time for the order, and ultimately the customer service. As will be pointed out later, up to 75% of the time delays in the OFP occur at these stages.

The basic functionality of this subsystem is to convert the orders in the order bank, excluding those on hold, into a feasible production schedule and finally into a feasible production sequence.

In detail, the three main processes are:

- **Production scheduling** (weekly), whereby the orders are assigned to certain build weeks in the different plants according to the available production capacity. The scheduling tool has to respect the overall mix and capacity constraints of the plants, as well as the top-level availability of the constraint entities, i.e. the number of engines available. To achieve this, the boundaries of a certain number of control entities are defined by the schedulers.

- **Production scheduling** (daily), whereby the weekly schedules are split up into estimated build days (EBDs). In this step the mix and change-over rules in the particular plant need to be taken into account.

- **Production sequencing**, which converts the EBD into a chain of production orders, that forms the final production sequence. There are different approaches used. Some plants generate one sequence for body, paint and assembly, whereas others generate different sequences for each of the production steps. The different sequencing approaches will be discussed in Chapter 6. In any case the sequence generation has to respect capacities and change-over restrictions,
batching rules to boost efficiency, and line balancing constraints to achieve maximum labour efficiency, as outlined in the example below.

<table>
<thead>
<tr>
<th>Constraint</th>
<th>Description Max.</th>
<th>Body</th>
<th>Paint</th>
<th>Trim</th>
<th>Final Assembly</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 door</td>
<td>3 in 5 cars</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>5 door</td>
<td>2 in 5 cars</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>ABS</td>
<td>2 in 3 cars</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Air/Conditioning</td>
<td>2 in 3 cars</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Automatic Transmission</td>
<td>1 in 13 cars</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Special Edition</td>
<td>1 in 10 cars</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Diesel</td>
<td>1 in 2 cars</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Electric Sun-Roof</td>
<td>1 in 4 cars</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>GTI Trim</td>
<td>1 in 12 cars</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Alarm</td>
<td>1 in 5 cars</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lateral Airbag</td>
<td>1 in 13 cars</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>TD Engine</td>
<td>1 in 28 cars</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

Table 5: Line constraints

The scheduling and sequencing tools are essentially heuristic search algorithms, which operate on an iterative basis and try to find an optimal solution, whilst respecting the constraints defined by the control entities. The daily scheduling and sequencing also can have significant manual input, whereby orders are swapped between build days according to needs.

Also, the orders in the system will have a priority attached to them, i.e. sold orders will have a higher priority than stock orders. Surprisingly, employee orders are prioritised over standard customer in some schemes, as it is argued that employee sales are 15+% of the total volume.

The algorithms use a set of criteria and priorities, for example:

- **Dealer given priority (0-99)**
- **NSC priority, given by the market to force or hold back single orders (optional)**
- **Employee/ non employee order (employee orders are priority)**
- **Sold orders as opposed to stock orders (pseudo dealer)**

The criteria for sold orders are:
1. **Order status**
2. **Dealer priority number**
3. **Sales type, incl. employee / non-employee classification**
4. **Time of order entry**

This sales priority list gives a pre-selection which usually cannot be implemented without alteration, as the material availability and plant requirements constraints have to be taken into account. Plant related constraints could be mix constraints (e.g. no more than 60% estates) demanding even distribution of labour, machine constraints (e.g. presses), etc. These criteria operate within the parameters already defined, which states the daily build volume per plant and the down-days, and the market and dealer allocations (fair shares).

In order to satisfy these different criteria the scheduler interferes in the order selection by defining several controls (‘commodities’). These commodities can be defined according to individual requirements and can be limited to a maximal value, and or to an exact value. Commodities basically force the algorithm to reselect the orders (after a system 're-run') according to the global settings and the newly defined commodities. This iteration is repeated until an acceptable solution is found. It is thereby aimed at keeping the number of controls to a minimum, since each one distorts the free order flow.
The secondary objective of the scheduler is to use constraint material or options to a maximum. If for instance supply of 90bhp engines is constrained, and only a certain allocation is given to the plant, the scheduler would check the overall number of orders for this engine, and if it exceeds the monthly possible build rate, it would ensure full use of this allocation.

There are a variety of difficulties for a BTO system induced by current scheduling systems, which essentially need to be solved to achieve a reliable and visible system:

- **Entity control.** Currently, order bank and scheduling tools operate on an entity-basis, which means that they do not see complete orders, but only the different entities (model, engine size, options, etc.). Hence there is no visibility provided to the scheduler as to what extent the orders are scheduled effectively in terms of throughput lead times. Even worse, the scheduler is not able to influence the distinction between sold and stock orders, as the throughput is controlled via the prioritisation scheme, whereby an order which is not scheduled in period A will receive a higher priority for period B, etc. There are certain VM-specific variations of the layout of the order bank and scheduling procedures, in any case the inherent complexity of the task and the quantity of orders to be processed limit the visibility of any particular order.

- **Constraint item utilisation.** The entity control system causes distortion to the seamless order flow by influencing the constraint item utilisation rates. Consider the case whereby the V8 engines are a supply constraint with a maximum daily capacity of 200 units. Hence the scheduler is tasked to use all of the 200 engines in his schedule. Since the V8 engine comes with standard leather seats, the demand for leather seats will be at a minimum of 200 units. If however other orders require leather seats, they will step automatically back in priority against the V8 orders.

This approach to scheduling can work only if the order bank has a certain minimum system fill of several days of orders (5+ days), which can be seen as a ‘comfort buffer’, to ensure that the algorithm has a critical order mass to generate the schedule.

In conclusion the entity control approach to order scheduling is highly distorting the seamless order flow and does not provide the scheduling personnel with the visibility required achieving reliable throughput times for customer orders. The system as it stands could best be compared to a fish pond (order bank) into which the different types of fish are thrown (incoming orders). Then, in order to fill the boxes for the next shipment (production schedule), the right size and colour of fish are fished out of the pond to fill the boxes, without seeing what other fish there are in the pond or how long these fish have been there. This lack of visibility and throughput reliability is unacceptable in a BTO system.
4.2.5 Vehicle Production

Vehicle production consists of three major processes and two interim buffers: the body shop, the body-in-white (BIW) store, the paint shop, the painted-body store (PBS), and the final assembly line.

The following table shows the different lead times in hours involved in the production process, what kind of paint batches are operated, and at which point the vehicle is identified with a specific order (order tagging point).

<table>
<thead>
<tr>
<th>Hours</th>
<th>Body FFD+BIW</th>
<th>Paint +PBS</th>
<th>Assembly+BIW-EOL</th>
<th>Total Minimum Plant Throughput Time in hours, including Buffers and Testing FFD-HTS</th>
<th>Average Paint Batch</th>
<th>Sequence Reliability Measure</th>
<th>Final Order Tagging Point</th>
<th>Re-sequeing Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>VM A</td>
<td>N/a 17.1</td>
<td>8 31.2</td>
<td>5-7</td>
<td>98% planned vs actual sequence</td>
<td>Assembly BIW, PBS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VM B</td>
<td>12 12</td>
<td>8.7 42.24</td>
<td>4-5</td>
<td>2% built on scheduled day</td>
<td>Body BIW, PBS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VM C</td>
<td>5.7 16.8</td>
<td>7.9 36.7</td>
<td>7</td>
<td>Not measured</td>
<td>Body Paint interim store, PBS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VM D</td>
<td>9.2 16.6</td>
<td>11.4 60.5</td>
<td>18</td>
<td>N/a</td>
<td>Assembly BIW, PBS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VM E</td>
<td>3.1 15.1</td>
<td>4.7 29.8</td>
<td>5</td>
<td>Not measured</td>
<td>Body BIW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VM F</td>
<td>4.8 10.4</td>
<td>5.2 20.4</td>
<td>6</td>
<td>10% planned vs actual, 90% within 6 hour window</td>
<td>Body BIW, PBS</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 10: Production System Lead Times

As the plants operate on different shift patterns, the throughput time needs to be set in relation with the shift pattern and the time of production start. For example a vehicle framed on Friday afternoon might have a significantly longer throughput time (in case of a weekend break), than a vehicle framed on Monday morning. Hence the data shown refers to the minimum total throughput time.

A major problem found with current vehicle production systems is the assembly sequence reliability, whereby in most cases it is almost impossible to predict the final sequence on the assembly track. As a consequence it is almost impossible to accurately plan the distribution of the new vehicles efficiently. As a countermeasure, vehicles currently have to be held for an average of 1 day in the plant to assemble the truck loads and achieve the required level of load efficiency.

The reasons for the unreliability of the sequence are:

- **Resequencing** of production in the BIW and PBS stores to achieve batches in paint and meet the assembly line balancing constraints.

- **Rework**, which holds up the individual cars and slots them back into the system at a later stage, when the rework task is finished. As the individual rework times are variable (i.e. only a spot-repair or a complete respray in paint), the time the vehicle will re-enter production is indeterminable. Additionally, vehicles could be subject to several hold-ups in production, lengthening their throughput by several days, as shown in the case below.

Table 5 shows a real example of the throughput of 569 orders, giving the scheduled build date versus what was actually handed over to sales, and where the vehicles are in the system. What can be seen is that 2% of the cars were built on the scheduled date and had been passed to sales. The production lead times have been taken into account in the calculation.

Insert extra column showing passed to sales at right of table and then move % pass to sales to last column.

<table>
<thead>
<tr>
<th>Time</th>
<th>Cum. % Pass to Sales</th>
<th>Not framed</th>
<th>BIW</th>
<th>Paint</th>
<th>PBS</th>
<th>Assembly</th>
<th>No of vehicles off-track</th>
</tr>
</thead>
<tbody>
<tr>
<td>On Time</td>
<td>2%</td>
<td>248</td>
<td>202</td>
<td>100</td>
<td>2</td>
<td>25</td>
<td>17</td>
</tr>
<tr>
<td>1 day late</td>
<td>22%</td>
<td>5</td>
<td>165</td>
<td>149</td>
<td>19</td>
<td>133</td>
<td>77</td>
</tr>
<tr>
<td>2 days late</td>
<td>66%</td>
<td>1</td>
<td>21</td>
<td>14</td>
<td>3</td>
<td>74</td>
<td>122</td>
</tr>
<tr>
<td>3 days late</td>
<td>88%</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>4 days late</td>
<td>91%</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 days late</td>
<td>96%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 days late</td>
<td>98%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 days late</td>
<td>98%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 days late</td>
<td>99%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 days+ late</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6: System Fill in Relation to On-Time Build
The rework levels shown in the following table refer to both the on- and off-line repairs at the body and paint shop level, and off-line repair for the assembly operation, which also includes the vehicles that fail the water, electricity and dynamic tests.

<table>
<thead>
<tr>
<th></th>
<th>Body</th>
<th>Paint</th>
<th>Assembly</th>
<th>‘First Time Right’ Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>VM A</td>
<td>N/a</td>
<td>15%</td>
<td>N/a</td>
<td>N/a</td>
</tr>
<tr>
<td>VM B</td>
<td>25%</td>
<td>15%</td>
<td>15%</td>
<td>54%</td>
</tr>
<tr>
<td>VM C</td>
<td>N/a</td>
<td>26%</td>
<td>N/a</td>
<td>/</td>
</tr>
<tr>
<td>VM D</td>
<td>62% OEE</td>
<td>20%</td>
<td>10%</td>
<td>57%</td>
</tr>
<tr>
<td>VM E</td>
<td>N/a</td>
<td>25%</td>
<td>N/a</td>
<td>/</td>
</tr>
<tr>
<td>VM F</td>
<td>2%</td>
<td>72%</td>
<td>7.8%</td>
<td>/</td>
</tr>
</tbody>
</table>

Figure 11: Rework Levels

In conclusion, the vehicle production subsystem itself is rigidly set by its layout and machinery and is basically unreliable. Current production methods therefore are in opposition to the core 3DayCar objectives, and the production process itself offers little or no room for time compression. Hence the research focussed on the feasibility of:

- **late order tagging** points, to save the body and paint lead times for customer orders, or even de-coupling the assembly operation completely from the paint shop.
- **approaches to create stable assembly sequence** which would permit the planning of truck loads before the vehicles physically leave the factory or assembly line, since information visibility is essential for a lean distribution system.

These issues will be further discussed in Section 5.

### 4.2.6 Supplier Scheduling

The supplier scheduling subsystem essentially has the function of communicating the component and material demand to the 1st tier and raw material suppliers.

---

2 Overall Equipment Effectiveness: Availability % x Performance % x Quality %
The VM issues a variety of different demand information, including forecasts, schedules, daily call-offs and sequenced supply messages. These different kinds of information originate from the various systems and steps in the order processing and scheduling process. Hence, the suppliers receive

- **The forecasts**, which are based on the VM Production Programme, which is at best a guess of what the actual production will look like. As pointed out before, the programme is a based often inaccurate sales forecasts biased by profit considerations, and rarely takes the order situation into account. The critical point here is the mix. The suppliers will in general receive up to 12 months forecast in addition to the contracted period, which in itself describes a rough volume outline to the accuracy of +/-15%.

- The **schedules**, which provide the supplier with up to 6-10 weeks’ forward information, based on the weekly production schedules and the system fill in the order bank. The schedules provide a rough guideline on the planned production per plant, but the exact build dates are still unknown, as the orders have not yet been assigned to a particular build date. Also, in some cases, the VM secures the raw material purchase of the 1st tier suppliers by guaranteeing to cover the cost of the latter, even if the material is not required.

- **Daily Call-Offs or DCIs** which are based on the daily production schedule (EBD). This information is provided 2-10 days prior to start of production and gives fairly accurate information. However, as the final assembly sequence is only determined in the PBS, the DCI is systemically inaccurate. Furthermore, any unexpected supply constraint can cause further rescheduling and late amendments.

- **SILS/JIT/Sequenced supply messages** are given with 2-8 hours’ notice and determine the final call-off sequence for modules and systems. These are to be supplied in the same sequence as the vehicles going onto the assembly track. Strictly speaking, only at this point in time are the ultimate requirements known to the supplier.

Due to the complexity of the information flow in the supply chain, there are two dimensions to be considered: **stability** and **consistency**:

**Stability** refers to the behaviour of the demand over time, i.e. how much the demand changes from day to day. For example, the demand might be 1,000 on Monday, 2,000 on Tuesday, 500 on Wednesday, etc. The stability can be measured in deviation from the average and applies to forecast and firm orders. However, as there are both forecast and firm orders, a second dimension needs to be considered – consistency of the demand information.

**Consistency** refers to the deviation of forecast to actual demand. For example, on 1/12/1999 a delivery for 1/1/2000 might be scheduled as 400 units, yet the actual call-off arriving on the 30/12/1999 only states 200 units for delivery on 1/1/2000. Consistency of demand is important to plan long term decisions such as capacity planning and in some cases even raw material purchases, which could directly affect the dynamics of the system. Furthermore the time horizons and detail given by the different types of information need to be considered. A schedule could provide 3 months forecast on a monthly or weekly basis, or the first month in weeks, the rest in months. Also, it needs to be considered at what stage the demand information is commercially binding, when does it change from being a forecast into a firm order, because only then are the actual requirements are known to the suppliers.
The supplier scheduling subsystem will be subject to further investigation as part of the 3DayCar Supply Chain study. However, the following preliminary conclusions should be noted:

- **Demand variability is built into the system**, as step-by-step the process alters from sales forecast to actual production sequence

- **The ultimate requirements are only fixed when the assembly sequence is determined** (which in most cases does not happen before the exit of the PBS). Hence modular and system suppliers, who supply their parts in sequence, have to be able to meet a call-off time as little as 2-8 hours.

### 4.2.7 Inbound Logistics

The inbound logistics subsystem does not directly interfere with the OFP, but will be subject to analysis within the 3DayCar Logistics Study in order to determine to what extent current logistics systems are capable of supporting a more responsive scenario. The following table briefly outlines the stock levels held at the vehicle manufacturers in the different systems to cover the variation in delivery and assembly:

<table>
<thead>
<tr>
<th></th>
<th>Small Parts</th>
<th>Standard Parts</th>
<th>BIW Parts</th>
<th>Engines</th>
</tr>
</thead>
<tbody>
<tr>
<td>VM A</td>
<td>0.5 - 2 weeks</td>
<td>3.5 days</td>
<td>3.5 days</td>
<td>2.5 - 3 days</td>
</tr>
<tr>
<td>VM B</td>
<td>Up to 1 week</td>
<td>Hours – days</td>
<td>N/a</td>
<td>1 day</td>
</tr>
<tr>
<td>VM C</td>
<td>5.5 days</td>
<td>5 days</td>
<td>N/a</td>
<td>1 day</td>
</tr>
<tr>
<td>VM D</td>
<td>N/a</td>
<td>1-3 days</td>
<td>1.8 days</td>
<td>1.5 days</td>
</tr>
<tr>
<td>VM E</td>
<td>N/a</td>
<td>1 shift</td>
<td>0.8 days</td>
<td>2 hrs dressed</td>
</tr>
</tbody>
</table>

|                | dressed     | engines       |           |                    |

**Table 7: Inbound Stock Levels**

### 4.2.8 Vehicle Distribution

Similar to inbound logistics, the vehicle distribution subsystem will be subject of the 3DayCar Logistics Study. However, the outbound logistics forms part of the overall OTD lead time for vehicles and has been included in the process maps and benchmarks. The benchmark taken was the minimum time required to transport a vehicle from the plant to a dealership in the UK.
4.2.9  **IT Systems**

While conducting the system capability analysis, a particular inhibitor encountered was the IT systems on which the process was hosted. In fact, the order needs up to 5 overnight updates on the computer systems, due to necessary code conversion and batch processing from entry to gate release in the factory. In particular, these steps include overnight runs for:

- **order generation** (code conversion)
- **order expansion** (into the Bill of Materials (BOM))
- **order scheduling**
- **order sequencing** (system update),
- **data transfer to traffic control system**

Another problem encountered is the use of different coding (e.g. ‘Keystroke’, ‘EOC’ (European Order Code), SFI (Special Features Indicator)), which are a legacy of past and non-standardised computer programming efforts.

The following figure shows a real-life IT system chart of a vehicle manufacturer. It visualises the magnitude of complexity and how the different IT systems interact. The arrows refer to ‘runs’ or batch updates, which need to be sequenced in order to ensure data accuracy.

![IT Systems Chart](image)

**Figure 14: IT Systems Chart, Example**

The systems research revealed the IT systems as a major inhibitor to both time compression in the order fulfilment process, and to change. The IT subgroup will further investigate the issue.
4.3 Summary - Generic Model

The following figure shows the OTD lead time capabilities for the different systems. The data shown encompasses 7 OTD systems, i.e. the 3DayCar sample plus an additional VM. It should be noted that the 7th OTD system was purpose-built with state-of-the-art technology in the mid 1990s with the objective of providing a 14-day OTD time for custom-built vehicles. The research clearly shows that this target was not achieved, and that this system operates in the same realms as the others, which have grown organically over time.

In conclusion, the OTD systems analysed are capable of providing a minimum lead time of 40.1 days for a custom built vehicle across the 6 sponsors, assuming all subsystems work at optimal throughput. The following figure shows the summary of the Big Picture Maps and the data of the comparative analysis.
Feedback allocation per market, allocation of constraint items

Production availability Material constraints

Sales request all markets all models

Central Planning Office

Production Programme for month M+2-3

Production Programme (for month M+2)

Sales forecast per market monthly submission

Sales forecast per market

Feedback allocation per market, allocation of constraint items

Central Sales Office

Request for Production Capacity

Yearly forecast, e.g. 12 week end

Monthly, Weekly, Daily, plus update / warning messages daily

Schedules according to boundaries set in production programme

Sequencing Tool in Plant or centrally. Approaches: fix sequence and resequence as required make bodies as per daily schedule, and create new sequence for paint and assembly

Order Entry

8.8 days [0.08-46]

Scheduled Orders 15.1 days [5-28]

Sequenced Orders 6.5 days [2-10]

Order Entry

3.8 days [1-15]

First Tier Suppliers e.g. 300-XX local content 20-60%

First Frame Date to End-of-Line, incl. testing, excl. rework time

Order Fulfilment Process

Generic Example

- Production availability
delay constraints
- Direct Order entry online feedback on build date online or day after
- Generally limited order amendment facilities: 2 weeks: engine, transmission
- 1 week: colour, trim days: some options

Stock Orders

Figure 16: Order Fulfilment Process, Generic Example

- First Tier Suppliers e.g. 300-XX local content 20-60%
- First Frame Date to End-of-Line, incl. testing, excl. rework time
- Production availability, delay constraints
- Direct Order entry online feedback on build date online or day after
- Generally limited order amendment facilities: 2 weeks: engine, transmission
- 1 week: colour, trim days: some options

The diagram illustrates the order fulfillment process, showing various stages such as order entry, production planning, scheduling, and distribution. The process includes feedback allocation, production constraints, and scheduling algorithms to manage orders efficiently.

Key points:
- Feedback allocation is essential for market and constraint item management.
- Production availability and material constraints impact order scheduling.
- Sales requests are handled at the central planning office, considering all markets and models.
- The production programme is scheduled for a specific period, typically three months in advance (M+2-3).
- Central sales offices are responsible for ordering production capacities, considering down-days, shift patterns, etc.

The document also mentions the input and output of the process, with feedback to order banks and stock orders. Production constraints, including stock orders, are critical for production availability.

Order Fulfilment Process - Generic Example

- Data refers to 30-day car sample, data collection March-December 1999
- Data format: Average [Min, Max]
- Data refers to calendar days, weekends, and holidays not considered
- Times quoted refer to minimum time required due to system settings or layout, not average time spent in the particular subsystem
- Overnight system updates are calculated as 1 day
- Production lead time is calculated as min physical system fill divided by hourly output and daily work hours
- Scheduled order are defined as 'firmly assigned to a build period', i.e. build week or day
- Sequenced orders are defined as 'firmly embedded into a production sequence'

Figure 16: Order Fulfilment Process, Generic Example

- First Frame Date to End-of-Line, incl. testing, excl. rework time
4.4 Demonstrated Best Practice

Norman and Stoker (1991) originally introduced the ‘Demonstrated Best Practice (DBP)’ approach as an additional tool for internal benchmarking. It assembles the best features of several systems to create a benchmark for a theoretical operation comprising the best features of each subsystem. In this case, the DBP map comprises of the best performing subsystems.

- Order Entry 1 day
- Delay in Order Bank 0.1 days
- Orders held in Schedules 5 days
- Orders held in Sequences 2 days
- Vehicle Production, FFD – EOL 0.9 days
- Consolidation for Transport in Plant 0.1 days
- Vehicle Distribution, Plant – Retail Outlet 1.5 days

**Demonstrated Best Practice: 10.6 days**

The DBP assembled out of the systems analysed is capable of an OTD time just below 11 calendar days. The reasoning behind the DBP is that if the best practice levels can be achieved at a certain subsystems in one scenario, it should be theoretically possible in any other scenario. Hence the DBP can be regarded as the best solution achievable over the sample size considered, with current systems & technology and market conditions.

4.5 Conclusion

The OFP mapping and benchmarking results have proven that current systems are incapable of delivering a custom-built vehicle in less than 40.1 days. Out of these 40.1 days 84% of the delay occurs in the information flow, and only 16% in the physical flow, as shown below.

![Figure 17: Time Delays for Custom Built Orders](image)

Manufacturing is clearly not the issue in terms of delays. The actual assembly operation only takes 6-8 hours, the complete production on average 1.4 days – including time for vehicle testing.
Also, the Demonstrated Best Practice generated from the results only provides a system theoretically capable of an OTD time of 10.6 days. However, in terms of the 3DayCar objective even the DBP is unsuitable and appears to be at least one step change behind the requirements. Hence the research suggests that a radically new approach is needed to achieve a BTO system with an OTD time of 3 days.

The following figure shows the percentage of UK customers willing to wait X days for their vehicle, split by manufacturer. What can be seen is a fairly consistent picture across all manufacturers.

![Customer OTD Lead Time Waiting Tolerance](image_url)

Figure 18: Customer Preparedness to Wait, Source ICDP

Comparing the system capability to the customer expectations in terms of OTD time waiting tolerances evaluated by ICDP for the UK in 1999, it clearly can be seen that the current supply systems are unable to provide custom-built vehicles within the expected lead time of customers.

In the current state scenario, shown in figure 19, the percentage of orders fulfilled over time constantly exceed the customers’ preparedness to wait, hence in theory all customers could be supplied within their waiting tolerance.
Assuming that 80% of the orders would be built to order under current system capability conditions, as shown in figure 20, a gap evolves in comparison to the customer’s preparedness to wait.

What can be seen is a gap between the expectations and the system ability to deliver vehicles, hence the VM might loose sales, as the customer might purchase a vehicle from a different brand with better availability.

The conclusion that has to be drawn is that current vehicle ordering and supply systems cannot support a higher degree of ‘built-to-order’ vehicles, as they are not capable of delivering responsive...
order fulfilment. If the degree of cars built to order were raised, customer service levels would dramatically drop. Therefore current systems are forced to rely on high levels of finished vehicle stock to provide a reasonable service to customers.

5 Product Variety & Complexity

5.1 Introduction

This chapter investigates current levels of product variety and complexity and their impact on the order fulfilment process.

Product complexity (as pointed out in the literature review in the appendix) is a key input factor to any manufacturing system. However, a distinct differential must be drawn between the variety of componentry used in manufacturing and the variety or choice offered to customers. Therefore the following discussion is divided into:

- **Variety** (‘offered choice’), which is the amount of model variations offered a particular market for a particular product (i.e. number of bodystyles, paints, trim, powertrains, and options)
- **Complexity** (‘build complexity’), which is the amount of variations of a product needed to produce the variety offered to the customer, i.e. the number of different body-in-whites, paints, powertrains, and options. This obviously can vary across plants making the same model, dependent on how many markets they supply. Nevertheless, the profile provides a basis for comparison of UK product variety, since all plants analysed supply the UK market.

5.2 Product Variety

The product variety analysis focuses on the variations offered in the UK market in 1999, comparing 23 models. The data recorded are the number of bodystyles, engines, powertrains, exterior paints, trim levels, paint-trim combinations and options offered. Out of these the total number of permutations was calculated, taking combination restrictions into account (i.e. no auto with 1.4 engines, air conditioning standard on GLX and GTI, etc.).
<table>
<thead>
<tr>
<th>Model</th>
<th>Year</th>
<th>Body-</th>
<th>Engines</th>
<th>Powertrains</th>
<th>Paints</th>
<th>Trims</th>
<th>Paint/Trim Combinations**</th>
<th>No of Options</th>
<th>Total No of Variances</th>
<th>UK Sales [ref year]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vauxhall Astra IV</td>
<td>1998</td>
<td>4</td>
<td>8</td>
<td>13</td>
<td>11</td>
<td>7</td>
<td>44</td>
<td>41</td>
<td>55,425,024</td>
<td>81,494</td>
</tr>
<tr>
<td>Vectra</td>
<td>1999</td>
<td>3</td>
<td>9</td>
<td>13</td>
<td>11</td>
<td>10</td>
<td>60</td>
<td>22</td>
<td>5,843,600</td>
<td>77,479</td>
</tr>
<tr>
<td>Rover 200</td>
<td>1998</td>
<td>2</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>6</td>
<td>60</td>
<td>10</td>
<td>14,960</td>
<td>64,928</td>
</tr>
<tr>
<td>25</td>
<td>1999</td>
<td>2</td>
<td>7</td>
<td>8</td>
<td>11</td>
<td>6</td>
<td>106</td>
<td>18</td>
<td>2,742,656</td>
<td>1,170</td>
</tr>
<tr>
<td>Ford Mondeo</td>
<td>1999</td>
<td>3</td>
<td>5</td>
<td>8</td>
<td>10</td>
<td>10</td>
<td>105</td>
<td>16</td>
<td>171,584</td>
<td>77,183</td>
</tr>
<tr>
<td>Fiesta</td>
<td>1999</td>
<td>2</td>
<td>5</td>
<td>6</td>
<td>13</td>
<td>11</td>
<td>63</td>
<td>12</td>
<td>22,368</td>
<td>99,830</td>
</tr>
<tr>
<td>Focus</td>
<td>1999</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>11</td>
<td>8</td>
<td>64</td>
<td>18</td>
<td>1,070,592</td>
<td>103,228</td>
</tr>
<tr>
<td>VW Golf IV</td>
<td>1999</td>
<td>2</td>
<td>7</td>
<td>9</td>
<td>14</td>
<td>16</td>
<td>211</td>
<td>22</td>
<td>154,964</td>
<td>63,715</td>
</tr>
<tr>
<td>Lupo</td>
<td>1999</td>
<td>1</td>
<td>4</td>
<td>5</td>
<td>8</td>
<td>18</td>
<td>85</td>
<td>10</td>
<td>176,576</td>
<td>4,642</td>
</tr>
<tr>
<td>MB E Class</td>
<td>1999</td>
<td>2</td>
<td>7</td>
<td>9</td>
<td>15</td>
<td>20</td>
<td>121</td>
<td>41</td>
<td>3,933,000,000,000</td>
<td>12,930</td>
</tr>
<tr>
<td>S-Class</td>
<td>1999</td>
<td>2</td>
<td>6</td>
<td>6</td>
<td>15</td>
<td>15</td>
<td>480</td>
<td>22</td>
<td>3,205,000,000</td>
<td>2,653</td>
</tr>
<tr>
<td>Nissan Micra</td>
<td>1999</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>9</td>
<td>4</td>
<td>36</td>
<td>5</td>
<td>1656</td>
<td>47,775</td>
</tr>
<tr>
<td>Primera</td>
<td>1999</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>10</td>
<td>6</td>
<td>60</td>
<td>2</td>
<td>820</td>
<td>21,714</td>
</tr>
<tr>
<td>Honda Accord</td>
<td>1999</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>8</td>
<td>10</td>
<td>30</td>
<td>2</td>
<td>529</td>
<td>19,024</td>
</tr>
<tr>
<td>Civic 5dr</td>
<td>1999</td>
<td>1</td>
<td>4</td>
<td>6</td>
<td>8</td>
<td>7</td>
<td>27</td>
<td>8</td>
<td>1348</td>
<td>31,596</td>
</tr>
<tr>
<td>Renault Clio</td>
<td>1999</td>
<td>2</td>
<td>5</td>
<td>6</td>
<td>13</td>
<td>7</td>
<td>91</td>
<td>6</td>
<td>1,514</td>
<td>63,991</td>
</tr>
<tr>
<td>Megane</td>
<td>1999</td>
<td>2</td>
<td>5</td>
<td>7</td>
<td>13</td>
<td>7</td>
<td>104</td>
<td>0</td>
<td>448</td>
<td>65,127</td>
</tr>
<tr>
<td>Laguna</td>
<td>1999</td>
<td>2</td>
<td>7</td>
<td>9</td>
<td>13</td>
<td>7</td>
<td>65</td>
<td>1</td>
<td>1,196</td>
<td>30,475</td>
</tr>
<tr>
<td>Safrane</td>
<td>1999</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>13</td>
<td>1</td>
<td>13</td>
<td>0</td>
<td>39</td>
<td>349</td>
</tr>
<tr>
<td>Peugeot 206</td>
<td>1998</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>14</td>
<td>9</td>
<td>43</td>
<td>14</td>
<td>7,520</td>
<td>58,788</td>
</tr>
<tr>
<td>306</td>
<td>1999</td>
<td>2</td>
<td>6</td>
<td>8</td>
<td>13</td>
<td>7</td>
<td>59</td>
<td>9</td>
<td>6,928</td>
<td>53,447</td>
</tr>
<tr>
<td>MCC Smart &amp; Cabrio</td>
<td>2000</td>
<td>2 (4)</td>
<td>3</td>
<td>4</td>
<td>8</td>
<td>5</td>
<td>40</td>
<td>8</td>
<td>15,348</td>
<td>n/a</td>
</tr>
</tbody>
</table>

* The data displayed is purely based on public domain vehicle brochures and other information material provided by the VMs and their UK retail outlets.
** Taking optional leather seats/trim into account
What the analysis clearly shows is that there is no correlation between the total number of permutations offered and the vehicle complexity in terms of powertrains, bodystyles, etc. The only correlation that can be proven is between the number of factory fitted options and the total permutations.

In fact, the total number of permutations is purely a result of the VMs’ policy towards the issue. As can be seen for the Japanese models, the variety is kept low by offering a high standard equipment level and few factory-fitted options. For other VMs the effects of so called ‘packaging’ can be seen, where options are offered only in conjunction with others (‘winter-packet’, consisting of fog lights and heated mirrors, etc.) through which a considerable complexity reduction could be achieved. Renault for example radically reduced their numbers of variations with the introduction of their ‘projet nouvelle distribution’ to a few hundred variations – mainly by packaging and model line rationalisation.

The main impact the product variety has on the order fulfilment process is obviously the probability of finding the correct specification of vehicle in finished vehicle stock – the more product variations offered the less likely it is to find the correct specification in existing stock. The next section investigates this issue in more depth, taking the distribution of demand into account.

5.3 Demand – Specification Pareto

Many levels of product variety are seen to be offered across different brands and models, yet the question investigated was whether demand was evenly distributed across each specification variation, or if the 80/20 or ‘pareto’ rule applies to the demand of vehicle permutations.

Our research shows that neither applies, as the demand does not distribute evenly, nor does the 80/20 rule strictly apply. In fact, there are generally three pareto curves that apply, one each for the derivative (i.e. body & powertrain), one for the option combinations (i.e. front fog lamps and CD changer), and one for the paint/trim combinations (red colour and black interior trim, etc.).

Hence plotting the distribution of specification demand in Figure 21, a very strong pareto character can be seen. Pareto relationships are stated for the following levels of variety:

- **Low variety**: less than 10,000 specifications
- **Medium variety**: 10,000 to 1,000,000 specifications
- **High variety**: greater than 1,000,000 specifications

Figure 20 shows that as a guideline:

- **Low variety**: 75% of sales are covered by 10% of specifications
- **Medium variety**: 75% of sales are covered by 5% of specifications
- **High variety**: 75% of sales are covered by 2% of specifications

---

3 80/20 rule: 80% of sales volume is achieved with 20% of possible specifications. This principle was first described by the Italian economist Vilfredo Pareto in the 19th century, and later became one of the 7 tools of quality.
A viable VM strategy is for a strictly reduced product variety and a pareto-like distribution of the demand potentially enabling the VMs to hold the ‘runner’ (What is this?) specifications in a finished goods inventory, and supply those from stock. Our research indicates that typically for a vehicle with 10k variations, 75%+ of the sales should be covered by 1000 variations.

5.4 Complexity

Technical complexity refers to the product complexity the plant has to deal with in order to provide the product variety offered to the customer. It is unfortunately difficult to draw direct comparison between the variety and complexity, as variety is specific to one particular market, whereas the complexity refers to the product supplied into several markets/countries, on average 60-80 different countries for a product.

Technical complexity can best be defined via the following key measures:

- Number of **body-in-white variations** used per vehicle
- Number of **paints** sprayed, hence defining the pre-assembly total complexity (BIW variations x colours)
- Number of **powertrains, trim levels, options**, etc. added to the car in the assembly operation, although this figure is very difficult to measure.

However, apart from these obvious factors there are others that affect the vehicle complexity:

- The **number of countries the vehicle is supplied to**, and hence the number of different country specific items ranging from LHD/RHD, daylight headlights on/off, engine emission levels, impact safety measures (different bumpers for USA) to more subtle differences of different paints for different countries, different paint quality requirements (especially for Japanese exports), and different standard equipment levels.
- The **number of technical changes**, which can add up to 130 changes per year, and significantly affect the stability within the plant.
Mercedes, who ship nearly 300k of its 1m vehicles every year to markets outside of Europe, mainly to the US, tried to overcome this problem by standardising all vehicles upwards. The aim was for all vehicles to meet the tougher American crash and emission standards, however, vehicles still need to be fitted with certain different systems that are affected by local requirements (e.g. suspension systems according to road conditions). It is estimated that these additional features add up to $1,200 additional cost per vehicle, which limits this approach so far to the luxury sector.

When Ford brought the Focus to the USA in 1999, the alterations required (Detroit News, 29th April 2000) involved changing 20% of the components, including headlights, taillights, sidemarker lights, speedometers, interior padding, minor modifications to the bumper, and worst: underbody modifications. The total engineering cost was estimated at $5m.

The main reason for the 3DayCar research investigating complexity, however, is the impact on manufacturing flexibility within the car plant and the implications for production sequencing. As pointed out earlier, the production sequence may be altered several times during the production of a vehicle to achieve economic batches in paint and a line-balanced assembly sequence which maximises labour efficiency. These rescheduling activities are necessary, due to the rework levels in body and especially in paint shop which distort the original sequence. On the other hand it is vital for a lean distribution system to provide stable and predictable destination/volume information, which at the moment is not available, hence additional cost is incurred with vehicle distribution. The sequence reliability requirement is clearly stated by logistics managers as 98+% in order to be able to plan effectively.

The necessity of achieving a stable sequence has been recognised by some VMs, and there are currently three major approaches on how to achieve it. Before discussing these issues however, a brief overlook is given of current levels of pre-assembly complexity and some of the reasons for the BIW variations.

<table>
<thead>
<tr>
<th>Model Segment</th>
<th>No of Body Styles</th>
<th>No of BIWs</th>
<th>No of Paints</th>
<th>Total Permutations Pre-Assembly</th>
<th>Different BIW for?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>RHD/ LHD</td>
</tr>
<tr>
<td>Sub-A</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>N/a</td>
</tr>
<tr>
<td>B</td>
<td>3</td>
<td>9</td>
<td>14</td>
<td>144</td>
<td>N</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>9</td>
<td>14</td>
<td>126</td>
<td>Y</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>158</td>
<td>10</td>
<td>1,580</td>
<td>Y</td>
</tr>
<tr>
<td>C</td>
<td>2</td>
<td>16</td>
<td>14</td>
<td>224</td>
<td>N/a</td>
</tr>
<tr>
<td>C</td>
<td>4</td>
<td>32</td>
<td>14</td>
<td>448</td>
<td>Y</td>
</tr>
<tr>
<td>C</td>
<td>5</td>
<td>36</td>
<td>14</td>
<td>504</td>
<td>N</td>
</tr>
<tr>
<td>C-D</td>
<td>3</td>
<td>243</td>
<td>10</td>
<td>2,430</td>
<td>Y</td>
</tr>
<tr>
<td>D</td>
<td>3</td>
<td>19</td>
<td>15</td>
<td>285</td>
<td>N/a</td>
</tr>
<tr>
<td>D</td>
<td>2</td>
<td>20</td>
<td>12</td>
<td>240</td>
<td>Y</td>
</tr>
<tr>
<td>MPV</td>
<td>1</td>
<td>4</td>
<td>13</td>
<td>52</td>
<td>Y</td>
</tr>
<tr>
<td>BMW, old 3 series</td>
<td>4</td>
<td>40,000</td>
<td>N/a</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>BMW, current 3 series</td>
<td>4</td>
<td>16</td>
<td>N/a</td>
<td>Y</td>
<td>N</td>
</tr>
</tbody>
</table>

Table 8: Technical Vehicle Complexity

BMW recently announced their new approach towards manufacturing complexity, which essentially relies on a reduced number of BIW variations (from 40,000 to 16) and a late order tagging strategy, enabling for resequencing in body and paint, and customisation of the vehicle only in assembly.

It can be seen that the overall complexity varies significantly across the models analysed, regardless of model segment. Clearly some manufacturers have made significant efforts to reduce
complexity which are related to the approaches discussed below. Surprisingly, the differentiation between LHD and RHD vehicles still induces further BIW variances. Although in two cases this difference has already be eliminated, same as for the different engines and air-conditioning.

The research suggests that technical solutions exist to limit the BIW differences to bodystyles and sunroof/non-sunroof variances only (if the roof is an integral part of the BIW).

The number of BIWs and paints are the critical input for the three approaches to achieve a stable production sequence, which will be outlined in the following:

- **Resequencing.** The resequencing approach sends a single production sequence into the body shop, where the vehicles will be produced as required and supplied into the BIW store. Out of the BIW the vehicles are re-sequenced into economic paint batches and sent into the paint shop. After the paint shop the painted bodies are sent into an automatic storage and retrieval system, which holds several hundred car bodies. By holding such a large number and being able to access any body at any time, the manufacturer attempts a re-sequence to the assembly track to restore the original production sequence given to the body shop. This is thus achieved through substituting and delaying vehicles. Average levels achieved are 98%. The final order-tagging is delayed until the vehicle enters the assembly track.

- **Volume-based or partial de-coupling.** Partial de-coupling uses a similar idea, whereby the orders sent into the body shop are supplied against the schedule into paint, and later into assembly. However, the final order-tagging is delayed until the exit of the PBS, which in this case has a conventional track-layout. The substitution therefore is rather more likely for the high-volume runners, than for lower-volume variations.

- **Complete de-coupling.** Completely de-coupled assembly operations mean to treat body & paint as ‘internal suppliers’ who provide vehicles into the PBS. The assembly simply takes the painted bodies out of the PBS as required by the incoming orders. The order tagging point therefore is at the entry into assembly. It is left up to paint & body to refill the PBS. Decoupled assembly operations provide good reliability and even potentially save throughput
time, as the orders do not have to pass through. This approach requires both a large PBS (typically 400 vehicles and more) and low vehicle complexity.

Summing up, it is possible to achieve a predictable assembly sequence, and even save throughput time in case of de-coupled operations, but with current centrally painted steel monocoque vehicles a significant technical investment is needed. In the future, spaceframes or other alternative body structures, that do not require central body and paint shop, are likely to be able to work with late order tagging points and de-coupled operations by default. Further detail on this issue can be found in the 3DayCar Spaceframe report.

6 OTD Time Compression – Concepts and Approaches

6.1 Introduction

This chapter briefly describes the major concepts and approaches currently found in the car industry on how OTD times can be reduced. These concepts or tools are not ‘exclusive’, i.e. certain approaches can be combined with each other.

6.2 ‘Kanban Supermarket’

The ‘kanban supermarket’ makes use of the demand-specification pareto curve described earlier on to supply the major runners from existing vehicle stock and to make the ‘repeaters’ and ‘strangers’ (i.e. the lower volume specifications) to order. By doing so, a range of advantages can be achieved:

- The majority of customers receive their vehicles within a short OTD time, as their high-volume variation is supplied from stock, hence the vehicle only needs to be allocated and transferred to the particular dealership.

- Production levels can be smoothed against potentially volatile demand by using the central stock as a buffer, without compromising customer service. If 80% are supplied from stock, the plants only need to cope with short-term variability for the remaining of 20%.

- If a vehicle is sold out of the central stock, a ‘kanban’ signal could be sent directly to the plant for stock replenishment. Like in a supermarket (which was the system that originally inspired Taiichi Ohno to introduce the kanban concept), the vehicle could then be simply replaced. Hence the plant would have a simple mechanism for stock orders whilst still working to customer demand.

There are two requirements for operating a ‘kanban supermarket scheme’; the ability to hold vehicle stock centrally in the marketplace available to all dealers and a rationalised product variety offering.

The concept is being successfully applied in several cases, and product variety in these cases is held below 10k permutations, generally offering high standard specifications and option packages.

6.3 Open Order Pipeline & Order Amendment

The open order pipeline refers to the concept whereby dealers are able to access all unsold orders / vehicles in the system (‘pipeline’). These orders could be unsold orders (not allocated to a customer) entered into the system by the NSC or other dealers. The open order pipeline essentially increases the chance of finding the right vehicle for a customer amongst stock orders.
The order amendment tool permits dealers or NSCs to change or amend orders already placed into the system according to customer requirements. For example, a customer might require a blue car, and the dealer locates an unallocated red car in the order pipeline. The dealer then allocates the car to the customer and amends the colour accordingly. Theoretically all features of a car are amendable (if the VM allows for amendments to be requested), but each feature might only be altered within different timescales. It was found that powertrains, trim levels and certain options have the longest amendment lead times, where amendments are allowed at all. Colour and low-impact options such as wheels and radio have the most flexible horizons. The following table shows three examples of the amendment timeframes permitted by the particular VMs:

<table>
<thead>
<tr>
<th></th>
<th>Engine</th>
<th>Option</th>
<th>Colour</th>
<th>Wheels</th>
<th>Stereo</th>
</tr>
</thead>
<tbody>
<tr>
<td>VM A</td>
<td>No amendment</td>
<td>No amendment</td>
<td>No amendment</td>
<td>No amendment</td>
<td>Amendment post-assembly at dealership</td>
</tr>
<tr>
<td>VM B</td>
<td>60 days</td>
<td>15 days</td>
<td>6 days</td>
<td>6 days</td>
<td>6 days</td>
</tr>
<tr>
<td>VM C</td>
<td>26 days</td>
<td>26 days</td>
<td>19 days</td>
<td>19 days</td>
<td>N/a</td>
</tr>
<tr>
<td>VM D</td>
<td>26 days, 42 days body</td>
<td>26 days</td>
<td>19 days</td>
<td>19 days</td>
<td>19 days</td>
</tr>
<tr>
<td>VM E</td>
<td>6 weeks</td>
<td>3 - 6 weeks</td>
<td>3 - 5 weeks</td>
<td></td>
<td>Amendment post-assembly at DC</td>
</tr>
</tbody>
</table>

While the open order pipeline and order amendment systems enable customer orders to be built as at the factory, they are essentially a sophistication of the old wholesale-driven system in which the order bank is filled up with stock orders.

The two concepts can be used in combination, although the research showed revealed that a wide-ranging order amendment facility is far less common than an open order pipeline.

### 6.4 Continuous Improvement

Continuous improvement strategies rely on a repetitive cycle of improvements, whereby it is aimed at continuously updating existing systems. The approach is a low-risk strategy, as hardly any step change will be made. Also, the old system logic will almost certainly be carried over into the updated system. Although improvements can be made, the breakthrough achievement is unlikely for the OTD time compression strategy.

This approach is generally found within VMs that operate a high-complexity policy, where variety reduction is seen as a decrease in offer to the customer. As a consequence, however, achievement of a high variety offering to customers relies on a high degree of custom-built vehicles. Sourcing from stock is unlikely since too many specifications would have to be held to enable customer satisfaction. On the other hand the variety induces complexity and longer OTD lead times into the scheduling systems, which are still, generally, wholesale driven.

### 6.5 Late Configuration and Postponement

Late configuration refers to the principle of customising a product after it has been built, i.e. finalising the vehicle specification post-assembly. A classic example here would be to fit the stereo at the dealership, or to have the body-work finalised at a separate configuration centre, where for example all GTIs are fitted with spoilers.
The general purpose of late configuration is to decrease product complexity within the actual production facility and to postpone configuration decisions. This postponement of configuration could then be used to shorten OTD lead times and to require less stock to meet customer requirements, since stock can be configured to provide greater choice.

The classic example where late configuration is applied in the car industry is MCC, whereby the car features a modular design, permitting to ‘plug-in’ the rev-counter and the clock, CD / radio and other extras. Also, the body panels can be replaced to give the car a new exterior colour. The Smart also features a ‘switch on/switch off’ module, as the gearbox can be bought in two variations, which are only software-controlled.

Other approaches to late configuration are to re-route vehicles directly after the line into special bays. Here, the vehicles receive additional body-kits and accessories (generally high-performance and special editions). This function can also be executed in distribution centres, where generally wheels, body-kits, accessories, entertainment functions, and selected interior parts are fitted.

However, there are two major problems inherent with this concept:

- **Double-handling**: This refers to the wasteful activity of fixing a part in the factory, only to replace it with another part at the point of customisation. This activity obviously is waste and bears the danger of compromising the vehicle quality during the replacement operation. Unfortunately for the car industry, the parts that are most likely to be suitable for late customisation (wheels, bumpers, steering wheels, gear knobs, etc.) are often those needed to be fitted in the factory, as the cars have to be moved. There is also a logistics problem in terms of the supply and backwards traffic, for instance, wheels which have been replaced. There are few parts for which a late configuration is feasible without incurring extra cost for double-handling, backflow of original parts or running the danger of compromising the vehicle quality at the configuration point (e.g. fitting an A/C at the dealer).

- The second issue is **inventory cost**. If parts were to be fitted at the dealer, the supply of parts would have to be ensured, and almost certainly some kind of inventory would have to be held at the dealer unless the parts are delivered inside the car and the dealer only needs to fit them. If the dealer has to hold inventory, not only the total inventory cost is relatively high due to the number of dealers, but also the parts stock redundancy risk might incur extra cost into the system, not to mention the parts logistics cost.

These additional costs must be compared with the cost savings due to the ability to achieve faster turnover of existing vehicle stock, or to reduce the absolute vehicle stock level and still give the same customer service. Otherwise the application appears limited to items such as radios, small body-work and accessories in general.
7 Conclusion

7.1 Current Supply Systems

- Vehicle scheduling and supply systems are mainly driven by the sales forecast, not by actual market demand for order build. Only 30% (over 3DayCar sample, UK 1999) of the vehicles were built-to-customer order, with 12% of these being adjustment to stock orders already existent in the manufacturer order bank.

- OTD system capability is on average 40 days, with 85% of the time delays occurring in the order scheduling and sequencing subsystems.

- The Demonstrated Best Practice, evaluated over the 3DayCar sample, shows a system capability of 10.6 days. Considering the objective of three days order-to-delivery for a custom built vehicle, a three-day car will only be feasible with a completely new logic of scheduling systems, and not a reengineered system.

- Manufacturing itself offers little potential for time compression, yet the unreliable body, paint, and assembly sequences compromise lean distribution and lengthen the logistics lead times. Alternative order tagging / de-coupling points can be used however to cut down lead times and give greater reliability to order sequence. An intermediate solution might be to use a resequencing approach after the paint shop to restore an original sequence, if the technical complexity allows for it.

- Complexity is a general problem, both in variety and technical complexity. The two most important factors identified are:
  - the number of body-in-white variations and colours sprayed, which determine the flexibility and potential sequence reliability within the manufacturing process
  - the total number of specification permutations offered in the marketplace, which determine a vehicle manufacturer’s ability to source certain vehicles from stock and is a major factor in the efficiency of line balancing and component stock levels.

The lower the numbers involved in these two factors, the more efficient production should be.

- IT system complexity and batch processing are further problems, introducing a minimum of 4-5 overnight updates for an order to go through the system. Also, the current system architecture inhibits change and improvement.

- The supply system is unable to provide vehicles within the current expected lead time of customers who are used to immediate availability from stock. Hence manufacturers have to rely on vehicle stock in the marketplace, as current systems are not able to provide built-to-order vehicles within an acceptable timeframe to the customer. Hence manufacturers might face the risk of losing sales, as customers might buy a different brand with better availability.

Redesigned systems are necessary if vehicle manufacturers are to embrace the philosophy of providing custom-built vehicles from the factory within an acceptable timeframe for all customers. Piecemeal improvement, as sometimes promoted as the way ahead, is simply futile, as the whole concept behind it is based on ‘push’ or wholesale supply systems, which also has left its legacy in the IT systems that have grown ‘organically’ alongside over the years.
The following figures show the current OTD times versus the customers’ preparedness to wait.

![Current Order Fulfilment Times v Customer Preparedness to Wait](image)

**Figure 24: Order Fulfilment Times v Preparedness to Wait**

The figure shows the current order fulfilment – dealer stock, central stock, order amendment and custom-built vehicles – weighted by their average sales and compared to the average waiting tolerance of customers. What can be seen is that, at the moment, OTD lead time is not an issue, as most sales are from existing vehicle stock. The inventory and discounts granted buffer the manufacturers and dealers against their inability to provide custom-built vehicles in a short period of time.

If manufacturers were to adopt a ‘build-to-order’ strategy using current systems, the result would be devastating for the customer service level, leaving a big performance gap, as illustrated below:

![Implications of 80% 'Build-to-Order' Content](image)

**Figure 25: Implications of 80% ‘Build-to-Order’ Content**
The supply system is unable to provide vehicles within the expected lead time of customers, hence the manufacturers face the risk of lost sales, as customers might buy a different brand with better availability.

The conclusion that has to be drawn is that current vehicle ordering and supply systems cannot support a higher degree of ‘built-to-order’ vehicles, as they are not capable of delivering responsive order fulfilment. If the degree of cars built to order were raised, customer service levels would further drop. So current systems have to rely on high levels of finished vehicle stock to provide a reasonable service to customers.

Redesigned systems are necessary if vehicle manufacturers are to embrace this new philosophy to provide custom-built vehicles within an acceptable timeframe for the customer. Piecemeal improvement, as sometimes promoted as the way ahead, is simply futile, as the whole concept behind it is based on ‘push’ or wholesale supply system, which also has left its legacy in the IT systems that have grown ‘organically’ alongside over the years.

7.2 The 4 Principles of a ‘Build-to-Order’ System

The current state analysis carried out in this research identified the following system requirements to support build to order production (BTO)

1. **Direct order booking systems**, whereby orders are directly transferred into the production sequence from the dealer or the internet. Direct booking into an assembly sequence is necessary to avoid distortions in the system caused by subsequent reshuffling and order swapping.

2. **Real-time information processing**, supported by an IT structure that does not operate on overnight batch processing. Different codes within IT systems also need to be standardised.

3. **All-time visibility of the production sequence** and the system fill of orders, provided to all players in the system (suppliers, logistics, dealers and customers!). Suppliers and logistics companies in return themselves must provide visibility for the VM to create viable schedules. For instance, the supplier would notify the VM instantaneously in case of a production constraint if the problem was not already visible within a totally open system.

4. **Minimal complexity.** This applies to both vehicle complexity and specification variety, as well as to standardisation of critical items in the system in general. For instance, modules, packaging, EDI data transfers, barcoding, and technological definitions (e.g. bus technologies) should be standardised. This has frequently been postulated but not generally implemented due to the real cost of complexity not being understood.

The Systems Stream research is currently developing such a system using direct order booking into an assembly sequence. Furthermore, the customer order should not be identified with the physical vehicle before the start of the assembly line (de-coupling), treating body and paint shop as internal suppliers to the actual assembly operation.

The direct order booking system will be validated using the simulation model. However, initial findings indicate that each manufacturer will require an individual solution to achieving an optimised order-to-delivery approach, with particular strategies or hybrid approaches being more suitable in one case than another.
7.3 The 5 Future Challenges for the Auto Industry

To achieve a build-to-order system requires not only a redesigned ordering and supply system, but first of all a significant change in company philosophy. Changing the mindset might prove to be even more of a ‘legacy’ than the redesign of outdated IT systems, as ‘build-to-order’ challenges the most established measures in the car industry - capacity utilisation and market share.

So far, the car industry has been getting away with ignoring customer demand by producing against forecasts and supplying from stock. We believe that in the light of overcapacity and competitive pressure in the world automotive industry this approach has reached its limit – and a ‘build-to-order’ strategy might prove to be just the cutting edge required to survive in today’s markets.

The author believes that there are five major challenges that need to be overcome to turn the legacy of ‘building to forecast’ into a responsive ‘build-to-order’:

1. **Abandon ‘push-based’ system mindset.** A new mindset with new key performance measures is needed, promoting customer service and total profit, as opposed to volume, cost and market share. Total costing of the complete order-to-delivery process is needed to discover sunk costs in the current system, which are not yet visible. This for example applies to the sunk cost of using steel mono-coques, which require high investments in R&D and facilities (press, weld & paint shops). The challenge is to resist overproduction and thus maintain margins and residual value, which are both essential to maintaining a strong brand. A build-to-order culture needs to be planted, to replace overproduction and discounting/incentive schemes.

2. **Enable demand-driven production:** Tactical allocation decisions must be separated from the operational order scheduling, and enable real-time and dynamic scheduling processes, or even direct order booking into the production sequence to ensure minimal order-to-delivery times. To achieve this, the organisational layout needs to be changed from a 'departmental chimney' structure to a cross-functional approach.

3. **Understand real demand** - and provide the appropriate service. The challenge is to both understand current demand structures and customer expectations, and to manage these expectations. This knowledge is essential to ensure the demand-driven production system is not subject to excessive variation. Differentiation in treatment of customer order segments is imminent, although heavily resisted by the manufacturers. However, with changes in the vehicle ownership model - manufacturers converting into a service mobility provider, rather than just being a manufacturer - this point will gain momentum.

4. **Information visibility & integration:** ‘build-to-order’ will not be achieved without integration of suppliers, retail outlets and logistics providers. For all, the provision of appropriate demand and production visibility is crucial, hence an online access to the order bank would be the logical thing. Also, adversarial behaviour and short term bidding needs to be replaced by long-term partnership. With the growth of ‘mega-suppliers’, changes in the power base in the supply chain are foreseeable in the near future.

5. **Break dependency on current Economies of Scale (EOS).** A major future challenge will be to escape the constraints of steel stamping and painting. Exploring other body structure and assembly techniques is a long-term challenge, yet will determine the ability to develop and produce profitable volume cars in a market with steadily decreasing life cycles and increasing variety. The standard steel mono-coque will need to be replaced by modular spaceframe or composite bodies, embracing modular assembly and supply strategies. Modules should be standardised across models and maybe even brands. Also, complexity and variety reduction will further alleviate R&D cost coverage requirements.
7.4 Future Research

While this report has concluded that a 3DayCar is not achievable with current scheduling procedures, production processes, and information systems, it has highlighted the inhibitors to such achievement.

It is believed that solutions can be found and that new technology is available to make a 3DayCar achievable within the next 10 years. The challenge is to prove that demand, complexity and systems can be cost effectively managed, together with the necessary changes in organisation, measures, costing systems and organisational mindsets and cultures.

Future research on the logistics and component suppliers, the simulation, and the organisation and finance streams will aim to consolidate this view.
Appendix A: Literature Review – Responsive Order Fulfilment

Introduction

The order fulfilment process is the central process of most companies, as it is defined as the ‘process from customer order entry to the delivery of the product to the customer’. Hence, it determines day-to-day customer service.

Apart from cost the order-to-delivery have become a focus of attention for many firms, with concepts like ‘agility’ or ‘responsiveness’ being added to traditional manufacturing strategies. Adding time as a variable to the manufacturing concept refuels the classic conflict, the trade-off between cost and flexibility. Manufacturing aims at long-term stability and in many cases repetitive or stability in product mix, the customer wants maximum service in terms of receiving his customised product in the right product specification within a minimum response time.

The model uses a systems theory approach to the order fulfilment process. Systems theory as an analytical tool was suggested by Emery (1969) and Melcher (1975), and has been previously applied by Checkland (1981). The order fulfilment process is modelled as an input-output process model, comprising of a set of subsystems and critical input and output variables.

Previous research and contributions originate from the following paradigms:

System Dynamics

‘System Dynamics’ research is founded upon the seminal work of Jay W. Forrester (1961), whereby time was proven to be a critical factor in supply chain performance. This research was further extended by Towill (1994, 1996) and Naylor et al.(1998), linking system dynamics to concepts like supply chain engineering.

Time Compression

The ‘Time Compression Initiative’ or ‘Time Based Competition’, which was initially promoted by Stalk and Hout (1990) and was adopted by a range of companies and academic researchers (for instance: Wilding, 1997).

Agile Manufacturing

The ‘Agile Manufacturing’ approach, which has its origins in the USA, where the term was introduced by the Iaccoca Institute (Goldman, Nagel & Preiss, 1995). Interestingly, the term ‘Agility’ or ‘Agile Manufacturing’ was used by the Iaccoca Institute to describe the adapted version of the Toyota Production System in the US auto industry, yet the term has migrated towards ‘responsiveness’ of manufacturing operations.

Agile Manufacturing promotes three major concepts to enable flexibility: to introduce ‘response’ buffers, to postpone decisions in manufacturing and to late configure products (Kidd 1994).

The two basic techniques with ‘agility’ are to:

Postpone the configuration of the product
Hold component stock to respond to incoming orders by assembling the product to order.

Similar concepts were introduced by Suri (1999) in his work on ‘Quick Response Manufacturing’, which essentially focuses on operations, and less on supply chains, and Katayama and Benett (1996) in their work promoting flexibility and responsiveness using what they call ‘Adaptable Production’. 
## The Lean Approach

Lean is a customer focus approach to managing a company or supply chain (Womack and Jones, 1996). Some observers, who confuse a few tools such as kanban with lean thinking, have suggested that the lean approach can only be applied successfully to repetitive and stable demand environments with low or medium product complexity (Harrison, 1999). However, to understand what the lean approach is, a descriptive ten point ‘not just’ plan is presented below.

<table>
<thead>
<tr>
<th>The Ten Lean Thinking ‘Not Justs’</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Not Just for component manufacturing.</td>
</tr>
<tr>
<td>2. Not Just a set of tools.</td>
</tr>
<tr>
<td>3. Not Just about shop floor breakthrough events.</td>
</tr>
<tr>
<td>4. Not Just for direct operators.</td>
</tr>
<tr>
<td>5. Not Just about Order Fulfilment.</td>
</tr>
<tr>
<td>6. Not just for predicable fast moving goods.</td>
</tr>
<tr>
<td>7. Not Just internally focused.</td>
</tr>
<tr>
<td>8. Not Just a standard formula.</td>
</tr>
<tr>
<td>9. Not Just a quick fix.</td>
</tr>
<tr>
<td>10. Not Just about processes.</td>
</tr>
</tbody>
</table>


In terms of a fit with responsiveness, lean thinking is well placed as the approach is about satisfying customer requirements, be they for efficiency or responsiveness as the first lean principle stated by Womack and Jones is to define value as perceived by the customer. If the customer demands responsiveness or immediate availability, such as in a supermarket, the inventory in the shelf does not represent waste, as it is necessary to support the customers’ requirements. Therefore ‘responsive’ is not incompatible with lean thinking as long as it is actually required by the customer, not the supply chain architect.

In fact, MacDuffie et al (1996) proved for the auto industry that lean plants are capable of handling greater product complexity in far shorter change-over lead times, which gives them potentially the advantage of responding faster to changes in customer demand than non-lean plants. Hence, it is then up to the car company to use this capability to deliver value to customer, as stated in the first lean principle.
De-Coupling / Decision Point Analysis

The Decision Point Analysis (DPA), developed from the decoupling work of Hoekstra and Romme (1992), is a technique used with both lean and agile approaches that is used to profile the current system of operations for a company and to test the feasibility of ‘postponement’ or the implementation of the Japanese-style kanban system (Hines & Rich, 1997). It is a technique that depicts the key point in the business where the ‘pull’ ordering of the customer meets the ‘push’ scheduling of the manufacturing facility. The decision point analysis map shows the key decision point trigger that affects the launch of materials and also the satisfaction of customer orders. For many products and groups of products, there is likely to be a single point that triggers all actions and the identification is the first stage in stabilising a manufacturing system. The point is also the origin of attempts to improve the flexibility of the production system by moving this point backward ‘up’ the internal supply chain.

![Decision Point Analysis Diagram](Image)


The DPA technique (Hines, Bicheno & Rich, 2001) focuses on the manner in which the factory is operated and uses a variety of classifications to characterise degrees of manufacturing postponement (delaying) the production of customer-specific products or orders. The map demonstrates a number of alternatives to the traditional systems of ‘push’ and ‘large batch’ manufacturing. It raises questions concerning the design of products (for late configuration) and also the processing reliability and efficiency of the internal factory assets (the use of manufacturing flexibility to displace excessive inventory holdings). The logic of this approach is quite simple and suggests that the trigger point can be brought further and further upstream as efficiencies in the latter operations is perfected. The approach is therefore one of backward integration and ‘de bottlenecking’ the internal supply chain. However, it should be noted that the technique is used to test the feasibility of such movements in the key decision point and is not used to eliminate all stocks. Instead, as the need to carry stock is lowered then the process stocks are lowered to a level that protects the flow, lead-time and customer service requirements. The bulk of the unnecessary inventory is moved backwards to protect the next target of de-bottlenecking or the new decision point.

Explaining the Chart

The illustration above shows 6 basic forms of manufacturing ranging from make to stock to make to order manufacturing.
At point 1, the manufacturing organisation is wholly dependent on forecasting routines and therefore schedules the movement of materials all the way from the initial processes to the finished product level. The implication of this system is that customer service is the result of availability of products or that the manufacturing process is slow and comparatively unresponsive (large batch sizes).

At point 2, the manufacturing organisation would use the internal processing lead-time (relative to the customer lead-time) as a means of satisfying orders as quickly as possible and at the last minute. The manufacturer enjoys the benefit of large-scale production (due to the customers taking the same product that is differentiated only by their particular packaging requirement).

At point 3 on the map, the manufacturer is holding a key stock in the work-in-progress stage and simply aggregates all orders due within the next shipment period to form the production schedule for the finishing processes. The pull is therefore satisfied by holding component stock.

At point 4, the manufacturer would use the high efficiencies and reliability of the finishing processes to draw materials from an intermediate stock holding point.

The fifth point of decoupling would involve the use of the primary processes as the launch point for materials (effectively operating the manufacturing system from raw material stocks held at the site).

At stage 6, the production process is highly reliable and responsive, due to the use of safety stocks contained in kanban areas. The next move for the factory is to manage the supply process and logistics of material orders arriving at the factory. In this scenario, the raw material inventories would be small and time phased (enough to cover for emergency events in the factory and to protect the flow of material conversion in the factory).

The mapping technique is useful to both the strategic management of a manufacturing business and also the operational management. This technique, when applied correctly and in conjunction with the other profiling tools, allows the ‘total’ integration of all managers during the later points of implementation (Hines, Bicheno, Rich, 2001). In this way, customer service through distribution logistics is the primary competitive weapon during the primary stages, manufacturing is the competitive weapon during the middle stages and inbound logistics becomes the final element of the system.

**P:D Ratio**

The ‘P:D Ratio’ concept has been popularised by Hal Mather (1992), although it was earlier mentioned in Japanese literature. As illustrated in the figure below, Mather defined P as the cycle time of the whole production process, and D as the time it takes to fulfil incoming customer orders. The ratio of these two values is the P:D Ratio, a key logistical parameter which Mather uses to define the appropriate production scheme.

In case P significantly exceeds D, then the stages of manufacture taking place up to the Point of Response can only be planned using a forecast, with the exposure of possible under or over production, or a wrong mix of production. To cover this eventuality, some form of stock must exist at the Point of Response in order to buffer prior operations planned and executed to forecast, from
subsequent operations driven by order fulfilment. This buffer stock is referred to as ‘Response Inventory’, so called because this stock is needed to respond to customer orders. It may exist as finished goods (either at the factory or in the distribution network), sub-assembly, parts or raw material.

From the P:D ratio Mather deduced five different manufacturing schemes can arising from different P:D ratios.

![Diagram](image)

The P:D ratio concept is probably the closest to actually quantifying the key variables that determine which order fulfilment strategy should be implemented by the company. However, there are certain problems arising with the concept, as it does not consider demand variability throughout the month and seasonality throughout the year. Hence the response inventory would need to be adjusted continuously or simply might prove to be inappropriate to the statistical uncertainty of the forecast, causing significant order problems, and the whole strategy would need to be recalculated to accommodate significant seasonal changes.

Also, product variety and the distribution of demand in relation to the specifications offered are neglected. This is a major downturn of the concept, as many companies nowadays operate differentiated stocking policies, whereby high volume ‘runners’ would be stocked, and low volume specification or ‘strangers’ would be made in case of demand only (see: Bicheno, 1998). In this sense, Mather’s model is too simplistic.

### Mass Customisation

Joseph Pine’s seminal approach to the problem providing individually customised products in mass production environments within an acceptable time frame for the customer. He argues that the greater the volume of production, the greater the tendency of the operation to simply provide standardised products only.

Hence, Pine (1993) proposes to use different points of customisation as a solution, to achieve the customisation whilst still maintaining volume production of standard products. He defines fives points of customisation:

<table>
<thead>
<tr>
<th>Customise service around standard products or services</th>
<th>Although standard products are used, customisation takes place at delivery stage in the form of additional services, e.g. airline seats (meals as additional service)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Create customisable products and services</td>
<td>Customisation is designed into standard products which customers tailor themselves according to their needs, e.g. office chairs</td>
</tr>
<tr>
<td>Point of delivery Customisation</td>
<td>Customisation happens at the point of delivery, e.g. fitting spectacles, developing photos. This type requires raw material or components to be held at the point of delivery.</td>
</tr>
</tbody>
</table>
Quick response involves integration along much of the supply chain. A classic example is Benetton’s holding un-died clothing until the actual demand is transferred via EDI, and then supplied on a quick delivery service. Inventory is kept in a partly processed state at a central factory, none in the distribution chain, and minimal is kept in the shops.

This long-established form of customisation simply involves assembly from standard modules. Examples are e.g. calculators or cars sharing the same platform. This might involve:
- Component sharing, where a variety of components is kept to a minimum by using group technology or design for manufacture
- Component swapping: cars with different engines
- Cut-to-fit modularity: e.g. made to order bicycles
- Mix modularity: combining several of the above
- Bus modularity, where finished components are combined via a bus system, e.g. hi-fi components

To achieve mass customisation, Gilmore and Pine (1997) suggest that there are four stages of customisation:

<table>
<thead>
<tr>
<th>Collaborative customisers</th>
<th>Work with customer in understanding or articulating their needs (a wedding catering service)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adaptive customisers</td>
<td>Offer standard but self-adjusting or adapting products</td>
</tr>
<tr>
<td>Cosmetic customisers</td>
<td>Offer standard products but present them differently. The same product is offered, but the customer specified sizes, own-labels</td>
</tr>
<tr>
<td>Transport customisers</td>
<td>Take on the customisation task themselves often without the customer knowing (providing the right blend of lubricant to match the seasons or wear rate)</td>
</tr>
</tbody>
</table>

Product Variety and Complexity

 Complexity and variety refer to both product complexity in terms of production, as well as to the product variety, which is defined as the number of product variances offered in the marketplace [Clark and Fujimoto (1991), MacDuffie et al (1996)]. A number of concepts are derived from this such as ‘mass customisation’ [Pine (1993)], ‘modularisation’ and ‘product platform strategy’ [Meyer and Lehnerd (1997)] and ‘late configuration’ [Ward et al (1995)].

Synthesis

In addition to these academic or consultant derived approaches discussed above, a number of industry based supply chain solutions have emerged; particularly concentrating on the food and grocery industry (Efficient Consumer Response), the textile or apparel sector (Quick Response), and the computer manufacturing (Kurt Salmon Associates, 1993; Hunter, 1990).

However, most of the concepts and approaches to responsive order fulfilment are prescriptive and tend to claim ‘global applicability’ (see for instance: Lowson, 1999). In the view of the authors this is highly unlikely, as every industry or even every particular company has individual characteristics or variables that determine its ‘optimal’ order fulfilment approach.
This paper tries to get away from any prescriptive solutions and postulates that there is an optimal order fulfilment strategy, which is exclusively defined by inputs, system settings and parameters for any particular supply chain at any particular point in its evolution. To do this, the seven stage SOFA model is introduced below which, by quantifying the key variables, aims at defining the appropriate order fulfilment strategy required in each particular cases.

In the opinion of the author there is no generally applicable approach but several key measures that determine whether an approach is suitable or not. These measures are input variables (demand or market related), system settings (the way the order fulfilment system is operated) the system parameters (lead times, processes, distribution, production related variables, etc.) and finally the output variables, which are the order fulfilment probability over time and the system cost. Although this contingent way of thinking about supply chains is not new, previous approaches have tended to be too simplistic (for instance, Fisher (1997), Mather (1992)) or remain in the realms of qualitative description (Naylor et al, 1998).

**Appendix B – Abbreviations**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATO</td>
<td>Assemble-to-Order</td>
</tr>
<tr>
<td>BIW</td>
<td>Body-in-White, the unpainted vehicle shell / body</td>
</tr>
<tr>
<td>BPM</td>
<td>Big Picture Mapping</td>
</tr>
<tr>
<td>BTO</td>
<td>Build-to-Order, which encompasses both MTO and ATO</td>
</tr>
<tr>
<td>DBP</td>
<td>Demonstrated Best Practice</td>
</tr>
<tr>
<td>EOL</td>
<td>End of (Assembly) Line</td>
</tr>
<tr>
<td>ETO</td>
<td>Engineer-to-Order</td>
</tr>
<tr>
<td>FFD</td>
<td>First Framing Date (for a vehicle in the body shop)</td>
</tr>
<tr>
<td>FTL</td>
<td>Full Truck Load</td>
</tr>
<tr>
<td>ICDP</td>
<td>International Car Distribution Programme</td>
</tr>
<tr>
<td>IMVP</td>
<td>International Motor Vehicle Program</td>
</tr>
<tr>
<td>HTS</td>
<td>Handover to Sales</td>
</tr>
<tr>
<td>JIT</td>
<td>Just-in-Time</td>
</tr>
<tr>
<td>MTF</td>
<td>Make-to-Forecast</td>
</tr>
<tr>
<td>MTO</td>
<td>Make-to-Order</td>
</tr>
<tr>
<td>MTS</td>
<td>Make-to-Stock</td>
</tr>
<tr>
<td>NSC</td>
<td>National Sales Company</td>
</tr>
<tr>
<td>OTD</td>
<td>Order-to-Delivery</td>
</tr>
<tr>
<td>OEM</td>
<td>Original Equipment Manufacturer</td>
</tr>
<tr>
<td>PBS</td>
<td>Painted Body Store</td>
</tr>
<tr>
<td>PTS</td>
<td>Pass to Sales</td>
</tr>
<tr>
<td>SMMT</td>
<td>Society of Motor Manufacturers</td>
</tr>
<tr>
<td>VM</td>
<td>Vehicle Manufacturer</td>
</tr>
</tbody>
</table>
References

- Forrest, J (1961), Industrial Dynamics, MIT Press, Massachusetts
- Harrison, A (1999), ‘The Role of Agility’, Logistics Focus, September
- Hunter, A , (1990), ‘Quick Response in Apparel Manufacturing’ Textile Institute, Manchester, UK


- Rother , M., and Shook, J., (1998), ‘Learning to See: Value Stream Mapping to create Value and eliminate Muda’, The Lean Enterprise Institute, Massachusetts, USA


