3DAYCar Programme

Paint Shop Survey

‘A report on the current state of automotive painting and its impact on customer order fulfilment’

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In the interests of continuous improvement the author welcomes any comments regarding the contents of this report and can be contacted at the address, e-mail or telephone number given on the front page.
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This report is confidential and restricted to official 3DayCar sponsors only. Publication or copying of the whole or any part of this document is forbidden without the express permission of the author.
Executive summary

- One of the key requisites of the 3DayCar is to minimise production lead-time, from the time a customer order is identified with a vehicle, until its completion in assembly. Another is to ensure that the planned production sequence of individual orders is reliably achieved. Since all sponsor manufacturers identify an order with a vehicle prior to the paint shop, it was decided to investigate the efficiency of this area of production.

- One of the primary objectives of the 3DC Paint Shop Survey was, therefore, to establish whether conventional Paint represents a bottleneck to current automotive production in terms of lead-time and sequence reliability. The survey found that in terms of the total bodies held throughout a plant from Body Framing to Final Inspection, an average of 40% are held in Paint and a further 22% in the Painted Body Store.

- The average lead time of the painting process is approximately 7 hours or one third of the total production lead time.

- The Painted Body Store (PBS) is used as a buffer between Paint and Final Assembly and serves two prime purposes: that of re-sequencing car bodies in order to achieve the optimum mix in assembly and holding additional stock in the case of defective painted bodies being sent back for rework. On average, 28% of all vehicle bodies are re-worked in some way, and 4% of painted bodies are recycled through at least a part of the Paint Shop. Two thirds of all problems in the Paint shop were considered by managers to be related to paint finish.

- Due to the absence of any universally recognised standards amongst VM’s, it is difficult to quantify precisely what level of waste the Paint Shop represents to the industry as a whole.

- Ideally, painting in batch sizes of one are desirable to build individual customer orders within a short lead-time. According to the survey, the current average batch size is 12 cars with a change-over time of 37 seconds. Smaller batch sizes are significantly more expensive in terms of lost paint, solvent and change-over time. Those VM’s who are currently using batch sizes of one are finding it difficult to meet legislatively required emission levels, which are being made increasingly tighter.

- It is more difficult to achieve a good surface finish with water or powder based paint systems compared to traditional solvent-borne systems on which the above statistics are based. Water-borne systems require longer colour change-over times than solvent and use more energy in the ovens due to the slower rate of evaporation. Given that these new paint systems are currently being installed by VM’s due to the environmental / legislative pressure, the task to achieve a reliable and cost efficient paint process is made more difficult.

- Achieving a high reliability system with batch sizes of one using the minimum of solvent is seen as the major challenge for VM’s aspiring to achieve true customer order fulfilment and the 3DC within current methods of body and paint production.

- The author suggests that two approaches towards automotive coating and finishing are emerging:

  1. ‘Incremental improvement’: using conventional systems, working towards a reduction of colour change-over time, batch size, emissions and waste and improving overall system reliability. This will be strongly assisted by the introduction of technologies such as automated sanding and spectro-photometry and the adoption of universal paint finishing standards and benchmarking
across the industry. However, movement to water-based paints and powder, encouraged by environmental legislation, will make such improvements more difficult to achieve.

2. **New Technology**: representing a step change away from conventional painting/production methods. This would utilise vehicle body frames that require minimal treatment in a paint shop together with thermoplastic body panels. These would be coloured during moulding and attached to the body frame on the vehicle assembly track.

- The Paint shop has always been viewed as part and parcel of the core vehicle production activity and currently represents around a quarter of the cost of the total facility. New developments are emerging in body construction that break the dependence on conventional high-volume, line based painting methods and these will undoubtedly be introduced over time to the benefit of the achievement of a 3DayCar. However, the sheer level of capital investment already sunk into European plants will ensure that rapid, radical change to the industry as a whole is unlikely.
1 Introduction: Why Paint?

The Paint shop has traditionally been associated with an industry that is ‘slow to change and suffering from under investment’. The application of industrial coatings in general manufacture is an activity that, until recently, has rarely been included in management research. The idea to pursue so specific an aspect in the first year of the 3DayCar (3DC) Research Programme was due in part to a number of discussions held with colleagues regarding current vehicle assembly methods and prime sources of wasteful activity. In this respect, the automotive paint shop was felt to be labour intensive, dogged by quality / reliability issues and surrounded by body stores.

Another key reason for choosing Paint is that a significant increase in vehicle complexity occurs when body colour is introduced. Vehicle painting is positioned in the middle of the production process between Body Framing & Final Assembly and is subject to a number of trade-offs involving batch sizes, line optimisation and body availability. The benefits to 3DC, therefore, were perceived not only in the examination of an expensive and wasteful activity, but also in one that potentially represents a major inhibitor to customer order fulfilment and building to order.

1.1 Aims and Objectives

The purpose of this report is to establish to what extent the paint shop represents a bottleneck during vehicle production. Using primary information collected from sponsor Vehicle Manufacturers (VM’s) its aim is also to investigate the implications of current and emerging automotive painting technology with regards to potential impact on 3DC. The following objectives are felt to be key in achieving this:

- Define the ‘current state’ of the paint shop.
- Identify the drivers of change in the industry (inhibitors & enablers).
- Establish to what extent Paint represents a bottleneck to production in relation to Body / Framing and Final Assembly.
- Analyse the implications of Paint on order lead-time and 3DayCar.

1.2 Methodology

This report has been compiled from the results of a questionnaire, semi-structured interviews and secondary information from Journals, Trade publications and Internet sites. It includes data from all participating VM’s and other paint related organisations. Whilst this effectively limits the findings to predominantly that of UK-based manufacturing, it is felt that the general nature of the automotive industry (i.e. pan-European / Global) should ensure broad applicability.

The relatively low number of automotive paint shops to be included in the questionnaire initially gave some cause for concern and the inclusion of other single-coat supplier paint plants was considered, such as 1\textsuperscript{st} & 2\textsuperscript{nd} tier suppliers. However, it was felt that body colour was a key issue and that the less complex paint systems might detract from the results.

\begin{tabular}{|l|l|}
\hline
Warwick Manufacturing Group, Dr Ken Young & June \\
Albion Pressed Metal (Thyssen Krupp Automotive) S.Wales & July \\
Ford Motor Company Ltd, Dagenham. & September \\
Honda of the UK Manufacturing Ltd, Swindon. & “ \\
Vauxhall Motors Ltd, Ellesmere Port. & “ \\
Volkswagen AG, Wolfsburg, (M. Holweg) & “ \\
Nissan Manufacturing UK, Sunderland. & “ \\
Peugeot Motor Company plc, Ryton. & October \\
\hline
\end{tabular}

A fully structured questionnaire entitled ‘Paint Shop Survey’ was prepared with the assistance of colleagues at LERC Cardiff University, consisting of both quantitative and qualitative orientated questions. The questionnaire (appendix A) was designed so that the short, qualitative answers at the front of the document could be completed before the meeting took place. Section 1 and 2 were intended as being predominantly relevant to the Paint Shop Manager. Towards the end of the document, however, more open-style questions were asked with a series of responses expected from a Quality and Planning Manager in an attempt to ‘triangulate’ the data.

1.3 Confidentiality

It is important to emphasise that this report and its findings are non-specific in terms of reference to individual VM’s in either text or data unless permission has been given to the contrary. As agreed during the 3DayCar Steering Group Meeting in Bristol, April 1999, there will be no direct benchmarking of performance indicators between individual organisations. However, a tacit comparison for internal quality audit purposes will be possible by sponsor VM’s, providing a record of the original response has been kept.

\footnote{3 A common technique used in research to ensure that one type of respondent cannot skew the results.}
2 Automotive paint and coatings

This chapter puts the paint shop in context with the automotive paint and coatings industry. It describes a number of aspects relating to the current state and introduces a number of key issues.

2.1 The Industry

The chart below shows total sales of industrial paint and coatings by major sector. Automotive painting accounts for 15% (31 million litres) of the total paint and coatings sales in the UK. A further 8% accounts for vehicle refinishing, performed after the vehicle has left production, usually due to crash damage or general repair work. Whilst there are some aspects of technology in vehicle refinishing that are relevant to 3DC, the prime focus of this report is covered under ‘automotive’.

![Figure 2 Sales volume of paint and coatings by major sector.](image)

Source: British Coatings Federation, 1997

Automotive painting includes work carried out at VM’s and Suppliers. Before the 1980’s, Suppliers tended only to paint metal parts and components with protective coatings, the application of body colour being the domain of the VM. Starting in the late 1980’s, plastic vehicle bumpers were the first major coloured sub-assembly to be painted by a supplier, initially to get rid of flow marks caused during moulding. Whilst bumpers are either painted in-house or out-sourced by the VM, suppliers have also begun to specialise in finishes such as ‘soft feel’ paints. Common parts that are coloured separately include dashboard mouldings & plastic bonnet fascias (Visteon) and door handles (ITW Fastex).

Matching painted plastic or composite parts to the vehicle body colour used to be a difficult task and one that until recently was done solely by eye. It is now much improved with the use of digital Spectrophotometry. This technology is now being used to assist rework in the Paint Shop of vehicle body panels in situ, where previously the whole body would be sent round the system again. This approach has created considerable savings both in terms of rework costs and time.

The complexity of the Paint Shop system means that performance is monitored by both VM and installation personnel. A typical installation is capable of delivering 60 painted bodies an hour, costs £75

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Paint Shop Survey

Confidential

million and is a ‘turn-key’ contract where sole responsibility from construction to initial trials is given to specialist paint finishing system engineering firms such as Durr.5

Figure 3: Paint finishing engineering companies in the UK

<table>
<thead>
<tr>
<th>Company</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Durr Behr</td>
<td>UK market leader, recently bought Inlac and Air Industry GEC.</td>
</tr>
<tr>
<td>Hayden</td>
<td>-</td>
</tr>
<tr>
<td>ABB</td>
<td>Paint finishing, particular emphasis on robotics.</td>
</tr>
<tr>
<td>Eisenmann</td>
<td>-</td>
</tr>
<tr>
<td>Taikisha</td>
<td>Brought into the UK by Honda, now supplying Toyota.</td>
</tr>
</tbody>
</table>

Paint

The three most common types of paint used in automotive manufacture are Water-based, Solvent-based and Powder. Water and Solvent based types consist of two main components, the ‘solid’ (colour) and the ‘carrier’ (water or solvent). Powder requires no carrier and is generally considered to be the most environmentally friendly despite the extra energy required in baking. Solvent-based is the least environmentally friendly on account of high ‘VOC’ (volatile organic content) which is known to be carcinogenic. Another method of coating application is the Electro-coat dip or ‘E-coat’, a process of applying a rust resistant primer to the bare metal body (the body-in-white) by totally immersing the vehicle in a large tank of liquid electrolyte whilst still being part of the track.

![Paint composition](image)

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
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<tbody>
<tr>
<td>1. Solid</td>
<td>Resin</td>
</tr>
<tr>
<td></td>
<td>Allows paint to dry</td>
</tr>
<tr>
<td>Pigment</td>
<td>Colour</td>
</tr>
<tr>
<td>2. Water, Solvent or Air</td>
<td>Carrier</td>
</tr>
</tbody>
</table>

2.2 Vehicle Painting

This section includes a brief description of the key paint processes that affect 3DC. Whilst some minor differences were found between the paint plants, the flow chart shown in figure 5 overleaf is indicative of the majority of plants studied in the survey. It is included to demonstrate the order of processes carried out in Paint.

Body Stores

Two body stores act as buffers between the three main stages of vehicle production: Body, Paint and Assembly. As each process has different manufacturing requirements, car bodies can be re-sequenced to pass through in the optimum order. For example, whereas Paint requires a line sequence determined by colour batch, Assembly’s requirements are based on the level of vehicle specification and labour content. All UK plants visited by the author had at least two body stores, with a capacity averaging 95 and 376 cars respectively at the start and finish of Paint. Some had a smaller, third bank just before top-coat application. Where this was the case, the BIW store was not sequenced, the Colour Store was sequenced for painting topcoat and the Painted Body Store set the Assembly sequence.

5 From discussion with Mr M Cresswell, General Manager, Inlac Finishing Systems (Durr), Warwick, 6 Oct 99
Body stores represent a significant inventory or ‘stock’ in the production process where vehicle bodies can be held from between 10 mins to 10 hours. Hines and Rich (1997) describe ‘waiting’ as the second of the seven commonest wastes within the Toyota Production System. Whilst the body store is currently a ‘Necessary but Non Value Adding’ (NNVA) operation, it also represents an opportunity for VM’s to improve either incrementally by reducing change over times, or radically through the adoption of new technology such as in-mould painting.

Dip tanks

After the vehicle body leaves the BIW store it passes through a number of dip tanks where it is initially cleaned of all grease and impurities, before being dipped in phosphate and passivative tanks (a form of galvanising) to protect the metalwork from corrosion. It is then sent through E-coat, which provides the ‘key’ for subsequent paint to adhere to, before being cured in an oven.

Dip tanks are a universal feature in all vehicle paint shops. It is convention that the use of the welded-steel monocoque in vehicle construction requires the whole body to be immersed in order for it to be protected. Whilst this is the most efficient means of coating where the body can remain part of the track, ‘total immersion’ may not suit all modes of construction that may develop in the future.

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large amounts of waste water and contribute to the forming of sludge deposits that require considerable environmental management before being fit for either re-use or safe disposal.

**Sanding and Sealing**

Sanding the body after E-coat and Primer is performed by hand. A smooth panel surface for applying topcoat is essential in order for the painted body to pass inspection. Whilst some automated sanding devices have been developed in North America, this is not the case in the UK where a significant proportion of Paint shop personnel are engaged in repetitive work in an unpleasant and potentially hazardous environment. Absenteeism in Paint was found to be running at higher than normal levels at a number of sites visited by the author. Sealing is required around all areas of the steel floor-pan and wheel arches, where spot-welded panels might allow the ingress of water during the life of the vehicle. Whilst this is a process that has been automated with extensive use of programmable robots, ‘touching up’ has still to be done by hand. Problems also occur with the sealer showing through the topcoat and failing inspection. Composite floorpans, a concept currently being considered by some VM’s, would eliminate the need for underbody sealing and would shorten production lead time.

**Primer, Top-coat & Clear-coat**

ESTA (Electro-static application) uses a ‘bell’ applicator head to produce a ‘mist’ of either primer, topcoat or clear-coat which is then attracted to the charged metal body surface. This is less wasteful of paint than the more conventional, spray-gun method which gives a better finish and is reserved for the final application of topcoat. After each coat is applied, the body is cured in an oven at temperatures ranging from 130 to 150 degrees Celsius. After the top-coat has been applied, a process known as ‘heated flash-off’ allows vapour from the paint to evaporate and disperse.

The use of solvent-borne paint has become a sensitive environmental issue. Whilst all the VM’s in the study were aware of their harmful impact, very few had begun to commit to water-borne paints. Installation costs aside, another key barrier to water-borne systems is the reduction in productivity by an estimated 30% due to the slower evaporation of water during flash-off. The amount of energy consumed by the curing ovens is also being examined by European legislative bodies where a proposed tax increase of 20% on energy use is being contested by VM’s.

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8 From discussion with Lotus Engineering, Norfolk, 27 Oct 99.
9 From discussion with Mr M Cresswell, General Manager, Inlac Finishing Systems (Durr), Warwick, 6 Oct 99
2.3 The drivers of change

This final section of the chapter identifies and examines the drivers of change and their impact in terms of enabler or inhibitor on 3DC.

Automation

In ‘Transforming Automotive Assembly’ Final Assembly is described, unlike machining, forming, painting or welding, as being a bottleneck and the ‘most difficult’ operation to automate in the automobile manufacturing process. It is reasoned that whilst the transfer of car bodies through a sequence of steps has been mechanised since the early 1900’s, direct assembly work itself has seldom been automated. Shimokawa et al. clearly feel that Assembly work organisation; the close interaction of robots, semi-automated equipment and workers, will be the major challenge in the early twenty first century.

There is evidence to suggest that Paint is also a bottleneck. The results in Appendix B of this report show that 40% of all cars in the production system are held in Paint and a further 22% held in the painted body store. The high proportion of car bodies held in the painting system is felt to be of significant interest for the 3DC and is discussed in more detail in chapter 4.

Achieving the correct ratio of manual-to-automated work will indeed present a major challenge in the plant as a whole. In the Paint plant specifically, the interests of safety and lowering absenteeism should be taken into account by reducing the manual content in unpleasant working areas such as sanding. Automation in the context of safety, reducing the number of bodies in the system and streamlining body sequencing is perceived as a key enabler in improving conventional Paint performance.

Quality

Consultant Mike Cowley suspects that the Paint shop and industrial coatings application will continue much as it has done in the past. Over the past few years, however, he notes the industry’s increasing competitiveness in cutting cost out of the system. With the exception of environment issues, the most significant factors in its drive towards commercial success are ‘reducing costs, increasing productivity and improving quality.’

Improving quality has been a key issue for paint plant managers. Whereas component defects are measured in PPM (parts per million), Painted Body rework is expressed as parts per hundred. When VM’S agree terms with Suppliers, performance targets of quality and delivery are considered as ‘given’, yet this is not the case within their own production plant. Adopting universally recognised common quality standards, a move that would require considerable VM collaboration, would enable benchmarks to be quantified from which individual Paint shops could measure their own performance and stimulate improvement. Maintaining the reliability of the painted body sequence through minimising rework due to defective paint finish is a key enabler towards the 3DC.


Capital Cost

Kreuzer & Milojevic state that the average automotive paint finishing line takes up between 20% to 25% of the total space of the plant. The complexity of paint systems is reflected in the level of planning and project management required during installation. With conventional paint plants costing one quarter to one third of the entire production facility (£75 million), what level of increase in current spending on Paint can be sustained? It is possible that outsourcing could be adopted where savings could be made by sharing the fixed costs with outside contractors.

Unit Cost

Current costing methods in Paint as in other areas of production still tend to be calculated on a ‘price per unit’ basis and little account is taken of the actual cost of moving car bodies or storing them. The historic reliance on the economies of scale and the extensive use of body stores needs to be re-examined if building to order is to become a serious proposition in manufacture. The current method of unit costing is seen as more of an inhibitor to 3DayCar because of its inability to account for ‘time spent waiting’ or ‘being moved’, both currently widespread occurrences in conventional painting.

Environment

In automotive production, Paint is the area of greatest concern to environmentalists because of paint waste, solvent emissions and energy consumption. Solvent-borne coatings remain popular because of the cost implications of replacing solvent-borne with new water-borne systems which often do not meet performance requirements. A high level of established expertise has built up around solvents such as ease of gun cleaning during colour changes and the use of solvent in spot repair booths; allowing rapid repairs to blemished panels and avoiding the need for a complete body re-spray. During the survey it was found that Paint Shop managers preferred solvent-borne paint on account of the ease of achieving an even, all-over finish.

In terms of 3DC, the optimal requirement of colour batch sizes of one would mean more frequent change-over and cleaning, leading to increased solvent emission levels. This would clearly be unacceptable for an industry already under pressure from existing legislation to reduce its emission and energy levels. Whilst there is some evidence of VM’s switching to VOC-free water-borne paint systems, it is found that such systems take longer to clean the equipment during colour changeover, longer to evaporate during curing and use more energy in the ovens.

In Europe, the Daimler Chrysler plant in Rastatt has developed what it describes as a ‘low environmental impact’ painting process. Working with BASF and DURR, the fully automated process includes lead-free primer and water-based paint where the clear-coat is composed of powder slurry. All three coats are applied ‘wet on wet’ thus requiring no energy input for curing. At the SMART Car factory in Hambach, powder coatings are used to paint the body. Compared with conventional painting, it is claimed that powder uses 50% less energy, produces 50% less waste and consumes 70% less water. However, both of the examples above rely on the use of large colour batches, around 20 to 30 cars, in order to minimise the time lost during cleaning and change over.

12 Kreuzer, B. & Milojevic, D. 1998 ‘Simulation tools improve planning & reliability of paint finishing lines’
Industrial Robot Vol 25 pp 117-123

Like most legislation, the degree to which the environment will act as an inhibitor to vehicle production and 3DC will depend upon the extent to which it is enforced. Concessions are currently being sought by some VM’s in the European court who feel current emission levels and proposed tariffs on energy use from Paint shop ovens are simply too severe.

**New Technology**

There have been a number of developments in automotive coating and finishing that have begun to explore possibilities outside of the conventional paint shop. In-mould painting, a process where colour pigment is injected into a mould containing the component, has been used for some time to produce wheel trims that require no further finishing. The Warwick Manufacturing Group is currently investigating ways that this could be used in moulded vehicle body panels.

The Daimler Chrysler SMART Car uses coloured plastic mouldings for 80% of its outside panels, only the steel frame requires a protective coating. GE Plastics, in collaboration with the SMART team, have developed the panels where the colour pigment is mixed with the polymer granules before moulding, producing a finish which is attractive, tough and resistant to scratching. Metallic finishes are achieved by means of a post-operation, requiring the application of a clear-metallic coat on the panel surface.

The increasing use of new materials, particularly plastics and composites, together with the emergence of alternative body construction such as the spaceframe offers new possibilities for VM’s. A spaceframe consists of a structural frame that accepts non-structural, detachable panels which can be moulded independently. The frame itself would only require a protective coating, vastly reducing the complexity of Paint in production.

The General Motors Saturn Plant in North America paints panels separately before attaching them to the body. In this case body and panels are soon re-united further down the track and all other aspects of production could be considered conventional. However, if all vehicle frames only required some means of protective coating and panels could be coloured as part of the moulding process, conventional Body and Paint Shops could effectively be eliminated. This would allow significant savings in customer order lead-time within production. New technology is therefore regarded as a major enabler to 3DC.

**Conclusion**

Customer order fulfilment, demand-led production and customer pull are all aspects of building to order that are central to 3DC research. The perception of the customer towards the 3DC and the future of personal mobility is currently subject to extensive research in the UK. Whilst average order to delivery time for UK customers being supplied by UK plants is currently around 35 days, this figure is expected to fall significantly in the near future.

There is little doubt that the transition from conventional, sales forecast-led production to building to order will have a significant impact on paint batch size, lead-time and waste. If simply reducing the choice of vehicle colours was acceptable to customers this would have the desired effect of optimising the painting process; indeed some volume manufacturers have already commenced model rationalisation

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programmes as a trade off between product variety and profitability. In reality however, most VM’s are currently faced with the ‘incremental improvement’ approach of adapting solvent borne, large batch sizes to water borne batch sizes of one.

New technological developments in the automotive industry, rising environmental concern and current European over-capacity point towards radical changes to greenfield sites in the future. The launch of SMART for example, with its coloured in-mould painted panels heralds a new approach to automotive production technology. However, for existing brownfield sites some with facilities over 20 years old, the challenge will be to continue waste reduction whilst meeting legislative requirements and maintaining profitability.

17 Renault has announced that its entire model range has been rationalised into around 8 customer option levels per vehicle.

18 Financial Times, 1999. ‘World Automotive Manufacturing’ November issue,
3 Survey Results

This chapter summarises the major findings from the Paint Plant questionnaire. 6 plants were visited and around 20 individuals interviewed. Complete tables of survey data are included in Appendix B. Some of the findings are of general interest, relating to the attempts by VM’s to move towards lean manufacture, others have significant implications for 3DC and are discussed in greater detail in the next chapter.

Whilst the survey consisted of a relatively small sample size, based pre-dominantly in the UK, the sites visited include major European manufacturers and Japanese transplants. Despite large differences in annual vehicle output, all sites represent volume production with multi-model lines. It is generally felt that the combination of site visits and the depth of response from the questionnaire captured the essence of the key operational and strategic constraints that govern automotive painting during daily manufacture. The final chapter explores the implications of these constraints in relation to 3DC.

3.1 Plant information

- Out of all plants visited, the average annual volume stood at a little under 300,000 vehicles a year. Annual volume ranges from 115,00 to 650,000.

- The average number of production lines served by a paint plant is 2. (Range: 1 to 4).

- The average number of vehicle models served by a paint plant is 3. (Range: 1 to 5).

3.2 Paint shop data

Pipeline Content

Table 2.1 in Appendix B shows the total number of car bodies held through out the plant. This is defined as from commencing Body Framing until the vehicle passes Final Inspection.

- An average of 684 vehicles (or 40%) of the total pipeline are held in Paint, defined as from leaving the BIW store and entering the Painted Body Store (PBS).

- An average of 376 (or 22%) of vehicles are held in the PBS.

Lead-time

Table 2.2 shows average lead-time per car body, defined as from commencing Framing until passing Final Inspection. Where more than one model was produced on one site, the respondent was asked to specify a lead-time closest to a ‘C-segment’ vehicle, e.g. VW Golf.

- Average Total Production lead-time per vehicle was found to be 20.1 hours.

- Average Paint lead time per vehicle was 7 hours (36% of Total) This excludes time spent in the PBS which varied from 10 mins to 10 hours.

Colour

Table 2.3 shows average Colour, Batch size and Change-over times.
• On average, 15 solid colours and 10 metallics are currently used in the Paint Shop.

• The average colour batch size is 12 cars. (Range: 1 to 20).

• The average change-over time between colours / metallics is 37 seconds, ranging from 10 to 71.

• Three of the VM’s mention that they have a preferred sequence of painting, where black was not desirable after a light colour, metallics had to be followed by certain colours and the ‘coloured primer philosophy’ had to be followed to gain the desired reduction in top-coat usage.

Quality & rework

The lack of a universally recognised paint finish quality standard makes attempts at inter-company comparison difficult. Also, some data received from the questionnaire was incomplete, particularly on costs. However, the data that was collected reveals the extent of the typical level of waste that currently exists in the paint shop:

• An average of 28% of all vehicles are reworked in some way. This ranged from 15% to 65%. Whilst these figures seem high, they also reflect the vast differences in the standards of paint finish deemed acceptable amongst VM’s.

• 4% of all vehicles need to be taken off-line and sent back through part of the system. This takes an average time of 38 mins.

• On-line repair takes an average time of 1.35 mins.

• In figure 6 below, Paint Shop managers were asked to describe the 5 most common faults in the paint shop. 70% of these were related to the quality of paint finish.

![Figure 6: Chart to show the most commonly occurring faults in the Paint shop:](image-url)

- Sequencing errors
  - Cars out of sequence

- Machine reliability
  - First run capability
  - Sealer robot problems
  - Excess sealer

- Quality of finish
  - Base coat dirt
  - Surface dust
  - Fibres
  - Water damage
  - Contamination
  - Top coat dirt
  - Sealer showing under paint
  - Runs
  - Sanding misses
  - Craters
  - Lean paint
Paint shop maintenance, Break-down & Labour levels

- Despite lacking a response in some areas of this section, paint shops currently require an average of 293 direct employees and 40 indirect. The latter refers mainly to service engineers from the installation engineering companies who work with VM’s on a permanent basis.

- An average of 26 hours a month is recorded as ‘breakdown’ time. Few VM’s have figures for Paint shop maintenance as this is normally on an ongoing basis.

3.3 Organisational Performance

The purpose of this section was to discover what the general opinion of staff who worked at the plant was in terms of the extent to which the paint shop represents a constraint to production. The graph below represents the overall results obtained from questions 3.01 and 3.02 in the questionnaire. It shows that out of Body, Paint and Assembly around 50% of managers generally consider the Paint shop to be the most disruptive.

![Figure 7: ‘Which of the following areas is the most disruptive to the production schedule?’](image)

In response to question 3.03 asking ‘what are the problems of introducing batch sizes of one as standard’ it is currently considered impractical even though one manufacturer is currently painting in batches of one. It is the impression of the author that the environmental pressure to move to non-solvent based processes will retard the movement to batches of one for a considerable period of time.

- ‘Loss of efficiency, the sequence would effectively lose a car.’
- ‘Waste of solvent & dumping of paint through excess emptying & flushing of the lines.’
- ‘Loss of volume’
- ‘Cost up, quality down’
- ‘It is the current standard…but we are looking at re-introducing batch’s because of costs/waste of material’
3.4 Environment

Solvent, sludge & waste water management and VOC / Incineration emissions monitoring & control are considered the main activities required to comply with environmental legislation in the paint plant. All plants are accredited to the general quality standard ISO 14001.

The survey found that Paint shop flexibility is felt by all managers to be affected by legislation, primarily in terms of emissions varying with model / colour mix. One respondent said: ‘solvent is great with paint, but the less you use the cleaner (i.e. no dust) the car has to be’. Another felt that significant batch sizes were required in order for his plant to achieve legal emission limits.

However, whilst a connection was made between environmental legislation and flexibility, none of the managers felt that current paint shop lead time was affected. If the question had been broadened to include the impact of water borne systems (as a result of legislation forcing VM’s to move away from the use of solvent) then lead times could be expected to increase with small batch sizes becoming unworkable. During the survey it was found that those VM’s who had installed water borne systems found that larger batch sizes were more economical due to the longer evaporation rates involved.

3.5 Production Technology

This final section of the questionnaire looks initially at what stage in production the body is assigned to a customer order and how this relates to the painted body sequence and the management of body buffers. It then examines the impact of technology on lead-time and flexibility.

Orders, sequencing and buffers

- Order segmentation generally begins two weeks before build commences. This requires the orders to be selected according to key Plant and Supplier constraints such as vehicle door configuration, model and sunroof option. One week before build the orders are sequenced, this involves spreading all critical options evenly across the days build and allocating each order a build sequence number which creates the Master sequence.

- Sequencing: To emphasise the difference between manufacturers in their sequencing strategy, two examples encountered during the survey were:

  1. Emphasis on levelisation (smoothing): in order to optimise the efficiency of each stage, the bodies are re-sequenced at Paint and Assembly. Reliant on body banks & buffers. Average Paint batch sizes. This means that significant buffer stocks of body in white and painted bodies are held to enable significant paint batch sizes of the same colour.

  2. Emphasis on keeping planned sequence throughout production: In order to maintain the sequence of bodies throughout the system, small paint batches are produced (reliant on rapid colour changes). Low buffer stocks are required for re-sequencing purposes.

- A significant example of a sequencing constraint includes one VM where, after painting a batch of sixty silver bodies, a ‘gap’ in the line equivalent to a further 60 bodies (1 hour) is required.

- Within Body and Paint, VIN numbers are usually only temporarily associated with a vehicle body, the ‘Car in’ number is used by some manufacturers as the reference number that remains permanently associated with the car. This is because orders can be swapped (‘substitution’) among common bodies to attempt to restore the Master sequence up until they leave the Painted Body store.
Technology, lead-time and flexibility

- All VM’s have some experience of water borne paint, either as E-coat, Primer or Top coat. However, the conversion to water from solvent based systems is seen by many managers as a gradual process, one of gathering experience in a new medium and not necessarily something to rush into due to the high costs of failure.

- The introduction of Paint robots is seen as increasing reliability & flexibility and decreasing defects.

- The increasing use of tracking systems, where vehicle information such as colour is transmitted from a ‘pod’ attached at the front of the body carriage, is seen as assisting in the overall control of the paint shop system.

- PBS repair booths and mini on-line repair stations are becoming common features, particularly on the sites visited by the author, as VM’s are recognising the importance of maintaining the production sequence. Unreliability through rework, with the resultant re-sequencing / substitution, is increasing cost and order lead time. 3DC estimates that only 60 – 70% of the original daily order schedule is usually achieved. Whilst the total elimination of defects in Paint would be preferable, by keeping as close as possible to the master sequence, production flow can be optimised up to and including the most complex process of all: Trim / Final Assembly.

- The use of ‘A/B’ systems is quite common worldwide, particularly on robotic paint systems with longer hoses, where one paint circuit can be cleaned whilst the other is in use. Whilst reducing colour change over lead-time to a degree, the danger of over-spray from the paint mist created by the previous body colour restricts further reductions to anything less than the time equivalent to one body.

Whilst all the respondents in the survey had heard of ‘new technology’ such as composites and thermoplastic in-mould coloured panels, very few had experienced it first hand save for the current painting of plastic bumpers. The major benefit of new technology was perceived by managers to be the replacement of some of the steel pressings to reduce the time required in coating and sealing in areas of limited access on the vehicle.
4 Implications for 3DC

The distinction between Paint shop constraints and those that affect 3DC is not immediately apparent. Lead time, complexity, quality, legislation and vehicle scheduling are all stand alone issues. The final chapter of this report includes, therefore, an examination of the extent to which the current state of Paint represents a bottleneck to short lead-time production and what prospects there are for true build-to-order and 100% customer fulfilment.

4.1 Bottleneck?

The survey shows that a high proportion of all car bodies are held in Paint, averaging around 40% of the total pipeline. The PBS also seems to hold large numbers at around 22% of total pipeline. Painting adds some value, but considerable complexity to the product, taking around one third of total production lead time whilst suffering from an unusually high level of rework. The sequence of paint colour itself creates scheduling constraints, particularly ‘light to dark’ and after using some metallics. As a proportion of total plant outlay, Paint is expensive to install and the industry is currently facing further costs of changing solvent borne systems over to water borne. At this level of analysis, it would be easy to conform to the view that Paint represents a bottleneck in current production.

The paint shop has been part of automotive manufacture for over fifty years and whilst it hasn’t evolved as rapidly as other aspects such as assembly automation, current demands for total reliability or batch sizes of one were not aspects of such importance in the past. The nature of Paint has changed relatively slowly as discussed in chapter 2, because for many manufacturers, it is only relatively recently that it has been asked to do anything other than paint large batches at high volume.

4.2 Batch sizes of one

Building to order for 3DC requires the capability of producing in colour batch sizes of one. However, this is currently undesirable because smaller batch sizes are significantly more expensive in terms of paint, solvent and time lost. If ‘smarties’ were introduced as standard into current systems, reducing the batch size from the current average of 12 cars to 1 would result in a very significant increase in the total changeover time from 3 to 37 mins every 60 car cycle 19. This approach would also create capacity problems due to the longer cycle times. Whilst one VM in the survey claimed to have come close to achieving single batch sizes, subsequent discussions revealed misgivings about their current system and the probability of changing back to larger batches.

The move towards installing water borne systems complicates further the implications of single batch sizes. Due to water taking longer to evaporate than solvent, more energy is used in the paint shop ovens. Thus, larger batch sizes of water borne paint would be required to save energy costs and reduce emission levels. In terms of a solution for 3DC, Paint would have to be taken ‘off-line’ and car bodies offered to production on demand and would entail holding inventories.

The whole issue of converting to water borne systems is fraught with problems of understanding terminology and thus can be misleading. There are many areas in the Paint Shop which require conversion, including the Primer, Base coat and Clear coat booths. However some managers in the survey, when referring to operational ‘water borne paint systems’, in reality meant only one area. The

19 Assumes changeover time of 37 seconds, current average from survey.
process of installing entirely new replacement systems, often whilst the existing one is still operating, is both time consuming and expensive and should not be underestimated in terms of inhibiting change.

4.3 Reliability

The reliability of Paint and its supply to the Painted Body Store performs a critical role in current production by maintaining the right body mix in order to sustain the sequence in Final Assembly.

Maintaining the optimum body sequence throughout production is vital in order to achieve required productivity levels. VM’s currently adopt two basic approaches: creating an individual sequence at each stage of the production process, or creating one sequence and then re-sequencing where necessary at Paint and Assembly. However, typically only 60 to 70% of the planned daily build schedule is achieved in terms of individual orders originally scheduled for that day. This is due to constraints such as paint inefficiencies, component supply, and assembly workload. Holweg (1999) suggests that re-sequencing and de-coupling are only interim measures to cover process unreliability. Therefore, it is suggested that the key requirements for a 3DC compliant Paint shop would be a reliable, powder/water borne system capable of delivering batch sizes of one, as illustrated in figure 9. All three requirements must be met before the system could provide the necessary flexible conditions for true build to order. From the evidence presented in this report, this appears to represent a significant challenge to VM’s at the present time.

4.4 Colour and complexity

Toyota is the closest to achieving 100% of planned build, from setting the master sequence at the beginning of production and sending bodies straight through Body, Paint and Assembly. Body stores are used as little as possible, but batch sizes of one are not yet standard in Paint, nor is the process fully water borne. Sustainable high quality and a low variance of model specification are key factors that contribute to the success of the Toyota Production System. Rationalising vehicle complexity and

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21 Discussion with Paint Engineer / Manager at Toyota, Burnaston suggests 95% of daily build sequence achieved.
specification levels can reduce the differences in labour content between models in vehicle assembly and therefore their dependence on re-sequencing. Reducing the number of body colours and BIW options is certainly a means of increasing the reliability of building the right car at the right time and increasing the efficiency of the Paint Shop.

However, vehicle rationalisation is also synonymous with reducing customer choice and the 3DayCar has to provide a solution for current specification ranges. Some VM’s in the survey appear to suffer from past strategies in carrying up to 4 variations of one colour. Japanese transplants carry less colours, but this is likely due to having been established later. VM’s adopt different marketing strategies in terms of colour choice. Europeans tend to offer many colours, giving a choice of up to four variations in the same colour, whereas the Japanese have always offered a restricted colour range for European markets.

**4.5 Two approaches**

From the general findings of this survey, two scenarios are put forward by the author as representing the current alternative approaches to automotive coating and finishing:

1. **‘Incremental improvement’**: using conventional systems, working towards a reduction of colour change-over time, batch size, emissions & waste and improving system reliability. This will be strongly assisted by the introduction of technologies such as automated sanding & spectro-photometry and the adoption of universal paint finishing standards and benchmarking practices across the industry.

2. **‘New Technology’**: representing a step change away from conventional painting and production methods. This would utilise vehicle body frames that require minimal treatment in a paint shop together with thermoplastic body panels. These would be coloured during moulding and attached to the body frame on the vehicle assembly track. VM’s will increasingly explore new strategies such as the SMART / in-mould painting route, rather than simply adopting conventional line-based painting. Thermo-plastic panels and pre-coated metals are also enablers towards the elimination of the Painted body plant.

3DC would benefit greatly from the ‘New Technology’ approach. Eliminating Body Framing and Painting in this way represents saving in order lead-time of around 12 hours. However, the prospect of greenfield sites with thermoplastic moulding technology and radical body construction strategies must be balanced with that of the current brownfield legacy and the very considerable inhibitor to rapid change that it represents. For many plants, ‘Incremental improvement’ will remain the only approach open to VM’s seeking true customer order fulfilment.

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Conclusion

This survey has established that conventional Paint Plants constitute a significant barrier to the achievement of a 3DayCar. The requirement to sequence body production against individual orders from the beginning of body assembly means that the lead time for a customer order is of the order of 20+ hours in production. The need for paint batching of bodies and the high level of rejection in Paint, means that it is difficult to build individual orders reliably within the overall time required for a 3DayCar. Incremental improvements must continue to be made in order to make the 3DayCar a cost effective proposition using conventional paint plants.

The emergence of new technology in the form of spaceframes and coloured thermo-plastic painted panels offers a major opportunity to the achievement of the 3DayCar because they would render the conventional Body and Paint shops basically redundant. The order lead time in production could be significantly reduced and the reliability of sequencing much increased. While conventional means of production will remain with us for many years, these new technologies in assembly are considered to be the way forward within the 3DayCar.
Bibliography


Journals and reports


GE Plastics Ltd (1999) ‘In-coloured Xenoy for the MCC Smart Car exterior body panels’ Internal report


Appendices:  A. The 3DC Paint shop questionnaire

B. Questionnaire Data
‘Hello and thank you for taking the time to read this. The 3Day Car research programme started in January of this year and is being supported by your organisation. I will be visiting your organisation soon and would like to speak to yourself and your colleagues regarding your paint shop facility. I would be most grateful if you could initially complete as much of section 1 & 2 as possible. I will go through the remainder with you when I come on my site visit.’

Mickey Howard, 3Day Car Technology Researcher, Bath University. Tel 01225 323682

OBJECTIVES
This questionnaire will be used to structure a number of on-site interviews. Its purpose is to understand the extent to which current painting methods represent a constraint on automotive production. Initially it requires paint shop data and then looks at more general performance levels from a wider organisational viewpoint. The study concludes with environmental issues and future developments. Please note that all information will be treated in the strictest confidence.

SECTION 1: Plant information
1.01 Company name / plant: ____________________________________________
1.02 Names of models produced: _________________________________________
1.03 Annual volume produced on site? _______ Number of assembly lines: _______
1.04 What was the average production leadtime per car from bodyshop to gate release_ hours.

SECTION 2: Paint shop data
2.01 What is the paint shop leadtime per car? ______ hours
2.02 How many cars are held in total in the system between bodyshop and assembly?__ cars
2.03 What is the capacity of the body bank before the paint shop? _____ cars
2.04 What is the capacity of car bodies between paint & assembly? _____ cars
2.05 How long does the car spend in this area? Range from ______ to ______ mins
2.06 What are the 5 most common faults in the paint shop? ________________________
                                          ____________________________
                                          ____________________________
                                          ____________________________
                                          ____________________________

2.07 What percentage of cars require rework in the paint shop? __ %
2.08 What is the average cost and time taken over rework per car in the paint shop? £_____ & _____ mins
2.09 What is the average time taken over rework per car in body pressing, welding and final assembly?

    Body pressing: _____ mins
    Welding:          ______ mins
    Final Assembly _____ mins

2.10 How much time per month is taken up through paint shop maintenance?   _____ hours

2.11 How much time per month is taken up through paint shop break down?   _____ hours

2.12 How many employees work in the paint shop, quality and off-line paint rework? ___

   ____ & ____ emp

2.13 What is the total number of colours, of which how many are metallics?   ___ co's___ metallics

2.14 What is the average paint batch size?   _______ cars

2.15 Is there any preferred sequence of colours during painting? If yes, describe:

_________________________________________________________________________________

2.16 How many paint booths are there?   __________

2.17 How long does cleaning the heads take?                            ___mins

2.18 How long is the total change-over time between colours? _____mins

SECTION 3: Organisational performance (to be asked during interview)

3.01 In your opinion which one of the following operations disrupts the production schedule the most: a) Body, b) Paint c) Assembly? Please state why:

    Paint shop Manager: ________________________________________________
    Quality Manager: ________________________________
    Planning Manager: ________________________________________

3.02 In your opinion, to what extent does the paint shop create waste for example in terms of defects, inventory levels, unnecessary processing or movement, and waiting? (1 = very little, 10 = very much)

    Paint shop Manager: ______
    Quality Manager       ______
    Planning Manager:     ______

3.03 In your opinion, what are the problems of introducing ‘batch sizes of one’ as standard?

    Paint shop Manager: ________________________________________________
SECTION 4: Environment (To be answered by the Paint Plant Manager)

4.01 What activities are required to comply with environmental legislation in the paint plant?

________________________________________________________________________

4.02 Is paint shop flexibility affected by this? If so how:

________________________________________________________________________

4.03 Is paint shop lead-time affected by this? If so how:

________________________________________________________________________

SECTION 5: Production technology

5.01 How is the painting sequence generated?

________________________________________________________________________

5.02 At what stage in production is the car body assigned to a customer order?

________________________________________________________________________

5.03 How does this correspond or relate to VIN numbering?

________________________________________________________________________

5.04 Do you currently use, or have you considered using any of the following paint technologies:

<table>
<thead>
<tr>
<th>Technology</th>
<th>In-use</th>
<th>Considering</th>
<th>Why:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water based paints</td>
<td>______</td>
<td>______</td>
<td></td>
</tr>
<tr>
<td>Electrostatic paint spray stations</td>
<td>______</td>
<td>______</td>
<td></td>
</tr>
<tr>
<td>Painting robots</td>
<td>______</td>
<td>______</td>
<td></td>
</tr>
<tr>
<td>CAD Simulation tools</td>
<td>______</td>
<td>______</td>
<td></td>
</tr>
<tr>
<td>Mini booths</td>
<td>______</td>
<td>______</td>
<td></td>
</tr>
<tr>
<td>Off-line programming</td>
<td>______</td>
<td>______</td>
<td></td>
</tr>
<tr>
<td>Ready painted modules (eg tailgate)</td>
<td>______</td>
<td>______</td>
<td></td>
</tr>
<tr>
<td>In-mould painted components (eg wheel trims)</td>
<td>______</td>
<td>______</td>
<td></td>
</tr>
<tr>
<td>Painted body sequencing tower</td>
<td>______</td>
<td>______</td>
<td></td>
</tr>
<tr>
<td>Outsourced / subcontracted paint facilities</td>
<td>______</td>
<td>______</td>
<td></td>
</tr>
<tr>
<td>IT / Telematics</td>
<td>______</td>
<td>______</td>
<td></td>
</tr>
<tr>
<td>Other:</td>
<td>______</td>
<td>______</td>
<td></td>
</tr>
</tbody>
</table>
5.05 In your opinion what is the potential impact of your choices above (5.04) on paint plant flexibility and lead-time?

________________________________________________________________________

Contact telephone number:__________________________

Thank you, this is the end of the questionnaire.
Appendix B: Questionnaire data

Section 1: Plant information

### 1.1 General plant information

<table>
<thead>
<tr>
<th></th>
<th>No. of assembly lines</th>
<th>No. of models</th>
<th>Annual volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>1</td>
<td>1</td>
<td>115,000</td>
</tr>
<tr>
<td>Mean</td>
<td>2</td>
<td>3</td>
<td>294,000</td>
</tr>
<tr>
<td>Max</td>
<td>4</td>
<td>5</td>
<td>650,000</td>
</tr>
</tbody>
</table>

Section 2: Paint shop data

### 2.1 Pipeline content

<table>
<thead>
<tr>
<th></th>
<th>Total in plant</th>
<th>Paint</th>
<th>% held in paint</th>
<th>BIW store</th>
<th>P.B. Store</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>571</td>
<td>274</td>
<td>30</td>
<td>61</td>
<td>86</td>
</tr>
<tr>
<td>Mean</td>
<td>1715</td>
<td>684</td>
<td>40</td>
<td>95</td>
<td>376</td>
</tr>
<tr>
<td>Max</td>
<td>2800</td>
<td>1300</td>
<td>46</td>
<td>156</td>
<td>1140</td>
</tr>
</tbody>
</table>

### 2.2 Lead-time per car (hours)

<table>
<thead>
<tr>
<th></th>
<th>Total Paint Shop</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>12</td>
<td>5.2</td>
</tr>
<tr>
<td>Mean</td>
<td>20.1</td>
<td>7</td>
</tr>
<tr>
<td>Max</td>
<td>28</td>
<td>9</td>
</tr>
</tbody>
</table>

### 2.3 Colours, Batch size & Change-over time

<table>
<thead>
<tr>
<th></th>
<th>Colours</th>
<th>Metallics</th>
<th>Av Batch Size</th>
<th>Av Change over</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>4</td>
<td>6</td>
<td>1 car/s</td>
<td>10 secs</td>
</tr>
<tr>
<td>Mean</td>
<td>15</td>
<td>10</td>
<td>12</td>
<td>37</td>
</tr>
<tr>
<td>Max</td>
<td>25</td>
<td>16</td>
<td>20</td>
<td>71</td>
</tr>
</tbody>
</table>

### 2.4 Rework

<table>
<thead>
<tr>
<th></th>
<th>Average rework %</th>
<th>Cost (£)</th>
<th>On-line (mins)</th>
<th>Off-line (mins) 4%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>15</td>
<td>-</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>Mean</td>
<td>28</td>
<td>-</td>
<td>-</td>
<td>38</td>
</tr>
<tr>
<td>Max</td>
<td>65</td>
<td>-</td>
<td>-</td>
<td>120</td>
</tr>
</tbody>
</table>

There was insufficient data to record cost of rework and average on line rework time.

### 2.5 Paint shop maintenance, breakdown & no. of employee’s

<table>
<thead>
<tr>
<th></th>
<th>Maintenance (hours per month)</th>
<th>Breakdown (hours)</th>
<th>No. of Employee’s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Direct</td>
<td>Indirect</td>
<td>Direct</td>
</tr>
<tr>
<td>Min</td>
<td>-</td>
<td>-</td>
<td>135</td>
</tr>
<tr>
<td>Mean</td>
<td>-</td>
<td>-</td>
<td>293</td>
</tr>
<tr>
<td>Max</td>
<td>-</td>
<td>-</td>
<td>502</td>
</tr>
</tbody>
</table>

There was insufficient data to record maintenance hours per month.