CHALMERS
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# Management of coloured parts and colour combinations in PDM systems

## A case study at Volvo Cars

Master's thesis in Product Development

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## Abstract

Today there is a trend of customising and tailoring products to fit the customers' requirements, which has led to mass-customisation among companies. In order to meet this trend and to provide a premium quality feel Volvo Cars offers a wide range of variants, options and details in their vehicle exteriors and interiors. An example is the combination of specific upholstery colours and materials and the colours of sewing threads and interior panels. This requires well-functioning information management in terms of managing a large variety and combinations of colours in a PDM system. Parts in various colours and materials that make up an exterior or interior are referred to as coloured parts. These parts are identical except that they differ in colour or material. Managing these parts in Volvo Cars' PDM system KDP has become problematic due to the complexity of the existing solution, which has led to a lack of knowledge among the users. The everyday tasks are also time-consuming and there is a risk of errors. There is a potential for improvements in this area. The complexity creates a challenge at the division of Product Lifecycle Management, where the responsibility for developing processes, methods and applications such as KDP lies.

The report examines how colours and colour combinations are managed in PDM systems today, based on reviews of publications and technology within the area. It also includes a thorough investigation of Volvo Cars' colour management, with listed strengths and weaknesses in order to get a clear view and deeper understanding of the current situation and existing solution, to be able to propose suggestions of improvements and recommendations. The report shows that there is a need for research in the area of colour management in PDM systems. Very few research publications of colour management in PDM systems could be found, which might be due to that companies use self-developed and customised PDM systems and that the information is confidential. The colour management process at Volvo Cars was found to comprise a rather complex solution within the PDM system that enables for automated creation of coloured part numbers from an uncoloured part, used as collector, which inherits part information to its coloured parts. In order to overcome this complexity and the lack of knowledge that it entails an alternative working procedure has been introduced. As short-term measures a set of continuous improvements are presented to reduce the manual workload concerning steps in the process and time for typing in KDP, and by stressing the need for instructions and better communication. However, in order to solve the complexity of how colours and colour combinations are structured and controlled in KDP an extensive and entirely new approach might be needed. It can be through for example a module outside KDP which provides for increased flexibility in user interface and functionality, with for example a library of virtual surface materials and another way of controlling the parts. Benchmarking and case studies of other companies within the automotive industry is recommended and would be beneficial.

## Preface

This report is a result of a master´s thesis project carried out at the Department of Product and Production Development at Chalmers University of Technology and for the division of Product Lifecycle Management at Volvo Cars Research & Development, Gothenburg, Sweden.

I would like to take this opportunity to express my gratitude to my supervisor and examiner professor Johan Malmqvist at Chalmers University of Technology for valuable support and guidance throughout the project. At Volvo Cars the project was supervised by Anne Viberg, Sr. Application Engineer at the division of Product Lifecycle Management, whom I would like to thank for supporting me by sharing knowledge and experience and providing useful contacts within the company. Special thanks are also given to Irene Gustavsson, Sr. Manager at the department of Operational Development, for giving me the opportunity to write this thesis. I would also like to give special thanks to the employees at the division of Product Lifecycle Management and to people who participated in interviews during the project. Their openness and willingness to give their time so generously has been much appreciated. Finally this master´s thesis has provided me with knowledge and experience in Volvo Cars and the automotive industry in general and in Product Lifecycle Management in particular, which I am truly grateful for.

Enjoy reading.

Oskar Kurtti, Gothenburg, Sweden, May 2015

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## Terms and abbreviations

| | |
|---|---|
| BOM | Bill of Materials |
| CAD | Computer-Aided Design |
| CO | Change Order |
| Colour management | Management of coloured parts and colour combinations in a PDM system |
| Colour coordinated part | Part with different colour or material depending on the vehicle´s interior or exterior |
| Colour system | Solution in KDP that creates and manages coloured parts for interiors and exteriors |
| Colour table | Defines the interior or exterior colour of the vehicle and includes S-codes and I-codes |
| Coloured complete part | Coloured parts that are assemblies (has at least one underlying part) |
| Coloured part | See colour coordinated part |
| Coloured single part | Coloured parts with no underlying structure |
| Coloured structure | Product structure with coloured parts |
| COTS | Commercial Off The Shelf |
| Delivery module | Assembly of delivery units |
| Delivery unit | Part or assembly as it is delivered and assembled in production line |
| DRM | Design Review Meeting |
| Function group | Top level in the product structure hierarchy |
| I-code | Ingoing code which is part of S-code(s) and defines the colour for each part in the interior or exterior |
| Interior matrix | Document specifying trim levels for upholstery in the different interior variants |
| KDP | KonstruktionsData Personvagnar (Engineering Database), Volvo Cars’ PDM system |

| | |
|---|---|
| Master sample | Physical specification that is a reference to the appearance and surface structure of a part's colour or material |
| OD | Operational Development |
| Part Folder | Electronic folder containing documents such as CAD models and master samples |
| Part list | Parts listed according to the product structure hierarchy |
| Part specification | Lower level of the product structure comprising part list with parts and assemblies with variants |
| PDM | Product Data Management |
| PLM | Product Lifecycle Management |
| POS | Middle level in the product structure hierarchy, below function group and above POST |
| POST | Lowest level in the product structure hierarchy, parts occur as delivery units |
| Product number | Numerical description of a complete vehicle |
| Product specification | Upper level of the product structure comprising product number and connections to variants |
| P-spec | Product specification |
| Product structure | Organises all components that make up a product and defines relations between product and part |
| Product type | Group of vehicle types |
| R&D | Research & Development |
| S-code | Superior code which groups I-codes and together with upholstery defines the colour (theme) of the interior |
| SML | Surface Material List |
| TcPMM | Teamcenter Product Master Management |
| TcVis | Teamcenter Visualisation |
| TPM | Technical Program Meeting |

| | |
|---|---|
| Uncoloured part | Part without colour information which acts like a collector for coloured parts |
| Uncoloured structure | Generic product structure with uncoloured parts |
| Variant | A variation of a part or product used to indicate a set of alternatives |
| Variant condition | Controls and defines the variant designation |
| Variant designation | Designation of a specific variant, e.g. left hand drive and right hand drive |
| Variant family | Group of variant designations, e.g. steering position |
| Variant package | Group variants from different variant families |
| Variant string | Lists variant designations for a specific part or product |
| VB | Vehicle Binder |
| VCC | Volvo Car Corporation |
| Vehicle type | Group of vehicle variants |
| Vehicle variant | A car or vehicle e.g. V60 or XC90 |

# 1. Introduction

This chapter presents an introduction to the master´s thesis project comprising a background to the topic and project, a description of the company Volvo Cars and the purpose, goal and scope of the study with research questions. It ends with a report outline to facilitate reading.

## 1.1. Background

Dr Michael Grieves, leader in the Product Lifecycle Management (PLM) field, emphasises the importance of information management when developing products and managing an organisation. He believes that with virtual representations of physical products throughout the products' lifecycles, companies can gain a competitive edge and the customers will be satisfied (Grieves, 2011). This was probably not as essential when Henry Ford, the American industrialist and founder of the Ford Motor Company, started to develop cars in the early 20$^{th}$ century. With or without this in mind, one morning in year 1909 Henry Ford remarked:

"Any customer can have a car painted any colour that he wants so long as it is black"

This famous quote is based on Henry Ford's idea of only building one model, the Ford Model T, with the same chassis for all cars. At first, the Model T came in only one colour, black, because the assembly line for mass production, which Henry Ford introduced, required it in order to maintain efficiency to keep costs down. The Model T was supposed to have a low sales price so that basically every one cloud afford it. Offering different colours would have been a risk by increased costs, due to a more complicated process by jeopardising the efficiency and quality of the production line. Due to this strategy Henry Ford could limit the aesthetics, by not offering a lot of options, and instead sell cars with the competitive advantage of high quality combined with a low price (Ford & Crowther, 1922). Despite disagreements within the company the idea proved to be a success factor. In 1927, the same year as Volvo's first car 'ÖV4 Jakob' was produced, the 15 millionth Ford Model T rolled of the assembly line in Highland Park, Michigan (History, 2010).

Today, about 100 years later, the customer desire has changed and requirements have increased continuously ever since. Customers want to have the ability to customise their own products. It is not only valid for typical tailored products as suits nowadays, but also for cars and computers. The trend of mass customisation enables value for the customer, but requires among other things flexible production systems with platform technology and development and information management (Gandhi, et al., 2014). One of Volvo Cars' corporate objectives is to "Provide a car that people want". With the brand strategy 'Designed around you', which is all about the customer and the human centric focus, their vision towards 2020 is to become a leading brand within the premium segment (Geely Sweden AB, 2014). In order to fulfil these statements and offer a premium quality feel a wide range of variants and details in the exterior and interior are essential. An example is the combination of specific upholstery colours and materials and the colour of sewing threads and interior panels inside the vehicle.

### 1.1.1. Problem definition

Due to the variety of upholsteries and interior details the number of unique interiors at Volvo Cars has increased from 113 in the model year 2001 to 221 in the model year 2016 (Volvo Cars, 2015a). For a Volvo XC60 there are 15 different upholsteries to choose from and besides that a flurry of other interior details can be chosen for each upholstery (Volvo Cars Configurator, 2015). This trend does not only apply for Volvo Cars. The Audi Q7 comes in 18 different upholsteries, and also here a wide range of other interior details can be chosen for each of the upholsteries (Audi Configurator, 2015). A key to Audi's success is the product model variety and the huge number of options that the customers can choose from, e.g. trim colours and interior colours and materials (Ludwig, 2014).

The wide range of interiors and exteriors offered has also led to a duplication of part numbers at Volvo Cars the past 5 years (Höglund, 2015). The same goes for Audi where part numbers increase rapidly and have more than doubled between 2005 and 2012. The fact is that no more than two Audis built in a year are identical. The theoretical variations for an Audi A3 is $10^{38}$ (Ludwig, 2014). The corresponding theoretical range of cars at Volvo Cars is more than $10^{10}$ (Volvo Cars, 2014).

Due to this variety of product models and the number of options there is to choose from for each model a lot of parts has to be managed in Volvo Cars' PDM (Product Data Management) system. Parts that are identical except that they differ in colour or material also has to be managed and treated individually. It requires a lot of part numbers and storage space, and all colour and material combinations that the wide range of options generate have to be structured and managed as well. This creates a need for well-functioning information management in terms of controlling a large variety and combinations of colours in the PDM system. At Volvo Cars the biggest challenge lies at the Research & Development department, where there is a request for making the colour management more comprehensible in order to increase the understanding, quality assurance and profitability.

### 1.1.2. Company description

Volvo Cars is a premium automotive manufacturer founded in 1927, headquartered in Gothenburg, Sweden. Since 2010 Volvo Cars is owned by the Chinese automotive manufacturing company Geely (Zhejiang Geely Holding Group Co. Ltd.). Volvo Cars is a global company that employs about 24 000 people (December 2014) and sold 465,866 cars in 100 countries around the world 2014. Today Volvo cars are produced in factories in Sweden, Belgium, China and Malaysia. Volvo Cars' brand strategy 'Designed Around You' is all about the customer and the human centric focus. The Safety vision '2020' states that "by 2020, no one should be killed or seriously injured in a new Volvo car model". The strategy towards 2020 is also to become a leading brand within the premium segment. When it comes to Research & Development (R&D), Volvo Cars has since 2010 been moving towards technology independence, meaning that Volvo Cars are gradually replacing Ford legacy technology (Volvo Cars was owned by Ford Motor Company 1999-2010) with technology developed in-house, with e.g. the new SPA vehicle architecture and the Drive-E engine family (Geely Sweden AB, 2014). Volvo Cars R&D department is responsible for the development of Volvo Car Group's car programs, comprising the use of thorough methods and the latest technologies, in order to develop vehicles in time with the right quality.

Within Volvo Cars R&D the Operational Development (OD) department, which is part of Program Management, covers the Product Lifecycle Management (PLM) division. The PLM division is responsible for developing and maintaining processes, methods and IT systems within the PDM area, throughout the products' lifecycles. They have process responsibility for Product Structure and Release Processes as well as External Communication.

## 1.2. Purpose

The purpose of this master´s thesis is to examine the current situation and information management within the area of colours and colour combinations at Volvo Cars Product Lifecycle Management division, in order to get a clear view and deeper understanding in the existing solution. The purpose is also to, based on findings and analysis of research and technology, propose recommendations of improvements.

## 1.3. Goal

The goal is to answer the research questions in *1.4.1. Research questions*, and present and document the project in a report containing:

- A state of the art analysis – A literature study within the area of product structure and colour management and an analysis of the available commercial technology within colour management
- A description of Volvo Cars' current colour management – Comprising a mapping of the theory and process, information model and needs from users
- An evaluation of strengths, weaknesses, opportunities and threats with the current colour management
- A list of recommended improvements and recommendations for future work

## 1.4. Scope of the thesis

The scope of the thesis is to conduct a thorough investigation of the current colour management within the framework and responsibility of the PLM division. The primary focus will be on how coloured parts and colour combinations are controlled when the structure is set and managed. The way that coloured parts are managed at Volvo Cars has been under development for a long time and it has been redesigned, highly customised, continuously since it was introduced. There is a need for mapping and interpreting the current situation and there is a potential for improvements in this area. An implementation of the recommended improvements is not within the scope of this thesis.

### 1.4.1. Research questions

The research questions presented below are the foundation for the content of the report. However, the content of the report is not restricted to these questions, it also concerns other areas for the purpose of increasing the understanding.

*RQ1: How are coloured parts and colour combinations managed in PDM systems?*

*RQ2: How does Volvo Cars manage coloured parts and colour combinations in their PDM system?*

*a) What processes, tasks, roles and information are used?*

*b) What are the strengths and weaknesses with Volvo Cars' existing colour management?*

*RQ3: How can the way coloured parts and colour combinations are managed at Volvo Cars be improved?*

## 1.5. Report outline

The report is divided into eight main chapters.

*Chapter 1. Introduction* – This chapter presents the background to the topic and project with purpose, goal and scope of the thesis, with research questions.

*Chapter 2. Methodological approach* – In this chapter a problem analysis is presented and the methods used throughout the project are described.

*Chapter 3. State of the art analysis* – This part presents a literature study within the area of product structure and colour management and an analysis of the technology Teamcenter PMM.

*Chapter 4. Findings* – In this chapter the findings from the secondary research and interviews are presented. It includes the theory behind the colour management at Volvo Cars, an applied example and a process model section.

*Chapter 5. Analysis* – This part comprises an analysis of the results from the findings and from in-depth interviews held during the project, in terms of a comparison between TcPMM and KDP, a comparison between two different working procedures and a SWOT analysis.

*Chapter 6. Proposal of improvements* – This chapter presents proposals of improvements, divided in to continuous improvements and extensive suggestions, derived from the findings and analysis.

*Chapter 7. Discussion* – A discussion comprising responses to the research questions, the project's validity and credibility, and the transferability of the results are presented.

*Chapter 8. Conclusions and recommendations for future work* – In the final chapter the project is concluded and recommendations for future work are stated.

*Appendix* – Appendices describing the roles mentioned in the report, the interview guide used for in-depth interviews, the full-size process models and an overall conceptual information model are found at the end of the report.

# 2. Methodological approach

The purpose and scope of the master´s thesis project together with the research questions and problem analysis had a central role in the choice of methods. This chapter presents a short analysis of the problem and the methods used throughout the project.

## 2.1. Problem analysis

The project need to investigate a complex information management process and ultimately propose improvements to the existing colour management in Volvo Cars' PDM system KDP. It requires a thorough mapping of processes, systems, roles and documents. Currently there is a lack of process documentation and the knowledge is concentrated to only a few expert users. It was thus decided that secondary research and interviews would be needed to capture the colour management process including the colour system solution in KDP. Quantitative data in terms of process performance was insufficient, hence qualitative methods such as a SWOT analysis was decided to be used for analysing. Further in order to generate suggestions of improvements through idea generation, evaluation and validation of suggestions it was decided that a design phase would be necessary.

## 2.2. State of the art analysis

A literature study was conducted, where research articles, literatures and other sources of information within the area of PDM, product structure and colour management were studied. It was conducted in order to get deeper knowledge and insight in the colour management area and to be able to know what publications there is to find and to know how coloured parts and colour combinations are managed in PDM systems today. Information was searched online in databases, journal articles and conference papers related to PLM. A new solution within the PLM system Siemens Teamcenter, Teamcenter Product Master Management (TcPMM), for managing parts and product structure were also investigated. In this case more specifically within the addressed product structure issues, the colour management area. Information was collected from discussions with Mikael Gustavsson at Volvo Cars IT and Olle Hansing at Siemens together with training material and instructions developed for TcPMM.

## 2.3. Mapping the current situation

A large part of the project was about getting information about the present state, mainly through interviews with employees working within the colour management area, but also through secondary research from written documentation and Volvo Cars intranet. The existing problems and flaws might be traced to how the colours are controlled in an IT system, but also to the process or working procedure in which the product structure is created, where different roles are involved and information is managed. Collected data were used to textually describe the current situation and to model the process. An applied example was also conducted in order to clarify and demonstrate the theoretical part. After that in-depth interviews were held in order to gain deeper knowledge, find areas for improvement and state recommendations.

### 2.3.1. Process modelling

The diagramming application Microsoft Visio was used for mapping the colour management process. Visio supports a wide range of standardised process methods such as IDEF0 diagrams, Six Sigma diagrams and TQM diagrams, as well as custom diagrams. Volvo Cars uses a customised approach in Visio when visualising processes and ways of working. This approach was chosen in order to use a standardised working procedure and symbols that are familiar with the company. Interviews and discussions with involved roles and information from written documentation formed the basis for the process models which were developed continuously in an iterative process. The colour management process was broken down to get a clearer view and understanding of the current situation and as support for continuing work when stating recommendations and developing improvements.

### 2.3.2. In-depth interviews

When the system was mapped and the process was modelled in-depth interviews were held. A purposive sampling strategy (Mack, et al., 2005) was used meaning that interview subjects were chosen in order to cover the roles that are a part of the process and that are in contact with colour management.

Interview subjects during the project were:

- Manager Product Documentation
- CO coordinators (3)
- Variant coordinators (2)
- Task leaders (2)
- Product modeller
- Application engineers (2)
- Purchaser

A description of each role can be found in appendix A. A total of 12 in-depth interviews were conducted. The interviews were held privately in group rooms at Volvo Cars. Each interview lasted for about one hour and notes were taken during each interview. Some interview subjects were interviewed several times, due to lack of time and in order to complement and confirm information. The notes from the interviews were transcribed to facilitate documenting and analysing. The interviews started with a short introduction to the master´s thesis project, where today’s colour management was described followed by a number of prepared questions. The interview questions are based on the objectives of finding the users’ perceptions, finding and focusing on what is unknown, finding weak spots to secure newsworthiness and focus the attention, quantify the manual workload, and to generate ideas. An interview guide was used to keep on track of the interviews and ensure the consistency. The interview guide can be found in appendix B.

## 2.4. Analysis

An analysis was conducted based on the documented findings in terms of the description of today's colour management, the applied example, the process models and the information models. The empirical data from the in-depth interviews complemented the analysis with detailed and specific input. In the analysis the raw data from the interviews was reduced and organised into separate areas of interest.

A short comparison of the colour management in TcPMM and the current colour management at Volvo Cars was conducted in order to see the similarities and differences between the solutions. When managing colours at Volvo Cars two different working procedures are used. These two working procedures were analysed and compared with each other, based on findings from interviews. A SWOT analysis was also used as a structured method for one of the working procedures, the one where the colour system in KDP is used. The SWOT analysis lists the critical strengths, weaknesses, opportunities and threats derived from the findings. Data based on facts were structured and current strengths and weaknesses, in terms of critical success factors, were stated as well as possible opportunities and threats, internal and external, in order to know where to focus the attention (Kotler, et al., 2005). The analysis formed the basis for the proposal of improvements and recommendations for future work.

## 2.5. Synthesis of recommendations and improvements

Information from the findings and analysis together with input from research and technology were used in order to brainstorm ideas for a list of potential improvements. Ideas of improvements were then discussed together with the supervisor at Volvo Cars, and the list of improvements were screened, refined and acknowledged. Some suggestions were excluded due to that they had been discussed earlier at Volvo Cars, or they are about to be implemented in the near future.

The list of improvements were divided into two different areas. One area comprising concrete suggestions of continuous improvements for increased colour management efficiency and one area of improvements with extensive long-term suggestions. Ideas of improvements which were more of recommendations character were listed separately in a conclusions and recommendations section.

# 3. State of the art analysis

This chapter presents a compilation of research articles, literatures and information from other sources within the area of PDM, product structure and colour management. It will be followed by an investigation of how Teamcenter Product Master Management (TcPMM) intends to solve the addressed product structure and colour management issues. It ends with a summary, which sums up and concludes the chapter.

## 3.1. Literature study – PDM, product structure and colour management

Most large automotive companies use long-established self-developed PDM systems, which manages the BOM information in an effective way. However, together with the CAD system it causes a siloed PLM approach, instead of a single source of information (SupplyChainBrain, 2015). Volvo Cars uses a PDM system called KDP to manage large amounts of information. With step-wise developed functionality the in-house developed system is used in order to meet upcoming and running needs and requirements (Svensson & Malmqvist, 2002). Other companies within the vehicle industry that uses self-developed PDM systems are for example AB Volvo, Scania, Daimler AG, Renault and General Motors (Tidstam, 2012). See figure 1 for an illustration of companies and their self-developed PDM systems, retrieved and illustrated from Tidstam (2012).

| Company | PDM-system |
|---|---|
| Volvo Cars | KDP |
| AB Volvo | KOLA |
| Scania | Spectra |
| Daimler AG | Smaragd |
| Renault | SIGNE |
| General Motors | GPDS |

*Figure 1 – Companies using self-developed PDM-systems* (Tidstam, 2012)

There is no doubt that in PLM the product structure for managing product variants is of high importance. What makes product structures complex is when products are available in different variants, which they usually are (Grieves, 2011). Dr Michael Grieves argues that product structures are arbitrary, but need to be consistent, and that there are many ways of creating a product structure for the same product. However, the importance lies in constructing and settling on one master product structure, in order to have a consistent approach within the company and for further development (Grieves, 2011). Vollmann et al. (1997) verifies this by pointing out a basic principle saying that companies should have one master product structure to manage and maintain as an entity. In the phase of creating Grieves (2011) claims that product structure is undoubtedly the most important information to establish. Two of the basic technical requirements of product structure management, as stated by Svensson & Malmqvist (2002), is to: ensure consistency and to support product variety. But why is it so important? According to Womack et al. (1993) the product structure plays an important role for the cost efficient delivery of customised product variants. In order to become successful in providing a large variety of products, in the IT infrastructure business function, Gandhi et al. (2014) argue that to increase the customer value and control cost customisation there is a need to: "Upgrade legacy systems in order to manage additional complexity of product and service attributes". Economies of scale, increased product variety and decreased impact from customer demands are other examples on advantages of successful product structuring (Avak, 2007). Efficient information management is also vital for reducing lead-times in today's rapidly increasing competition in the automotive industry. Product structures are also critical to create and manage due to that different departments within the organisation have different requirements and demands. This requires clear information management strategies. In a product structure management strategy the company's different internal interests, as well as external stakeholders have to be considered (Svensson & Malmqvist, 2002). Svensson & Malmqvist (2002) emphasises the need for workflow support and information that integrates processes. The challenge is also global production which put demands on a well-functioning PLM system (Ogewell, 2015).

At Volvo Cars the significance of the product structure is described in Volvo Cars Business Management System (Volvo Cars, 2015b) as follows:

"A comprehensive and common product structure for the whole company is a prerequisite for meeting both the internal efficiency and lead time requirements and the external legal and traceability requirements. The product structure is the foundation on which marketing, product planning, product development, the handling of orders, purchasing, production and aftersales activities within VCC are based."

In order to increase product variety and keep costs for mass customisation close to costs for mass production, companies introduce platform development and modularisation thinking into product design. To become successful companies must consider the product variety in relation to the internal complexity that it entails, especially when it comes to information management. Therefore the product variety has to be reduced but not at the expense of the customer satisfaction. One has to balance the external variety by means of studying the customer perceived value (Daaboul, et al., 2011). Product flexibility put companies' supporting information systems to the test through the growing number of product variants that must be managed (Waschler, et al., 2002). Daaboul et al. (2011) also argue that the large product variety has direct impact on cost and lead-time. However, cost and lead-time in its turn impact the customer's perceived value. The main issue is thus to find the balance between variety and the complexity that it generates (Daaboul, et al., 2011).

But how is efficient PLM achieved? According to Grieves (2011) there are three primary components that have to be stressed for efficient PLM; technology, processes/practices and people. For technology the key is the virtual representation of the physical product throughout all phases of the product's lifecycle. The technological evolution increases the virtual capabilities as well as the computing capabilities (software in products), which leads to intelligent and autonomous products. Processes are the route to productivity, innovation, quality and collaboration. Here automated processes are the key, which makes us more productive, efficient and lean. Due to new technologies more processes can be automated. People are the most important component of PLM, but the least beyond our control. It does not matter if the technology and the processes are working smooth if not the people working in an organisation are using the technology and processes properly, and are adaptable to changes. People are by nature opposed to change, which means that organisation and leadership plays an important role when it comes to people and adaptation to technology (Grieves, 2011). Grealou (2015) presents fifteen pillars of effective PLM delivery management. Among these fifteen stakeholder management, change management, quality assurance and communication are mentioned. All stakeholders and their interests have to be identified, thorough change processes to manage changes as well as quality standards and knowledge sharing have to be applied. Efficient PLM is also achieved through a defined communication strategy as the business transforms, e.g. when implementing new processes. Another way is to conduct business impact assessments when e.g. changes are made. Education and training also plays an important role (Grealou, 2015). Bokinge (2012) lists a number of guidelines for PLM solutions, which can be used as recommendations for efficient PLM. One guideline concerns the importance of the stakeholders in terms of defining the benefits for all stakeholders. As was stated earlier Grealou (2015) also highlights the importance of stakeholders as one of the pillars of effective PLM delivery management. Other guidelines for PLM solutions mentioned by Bokinge (2012) are to aim at satisfying rather than optimising and to reduce the degree of customisation. It is also recommended to establish consistency in the PLM architecture. These guidelines for PLM solutions could be used to evaluate how an organisation's PLM solution correlate to these guidelines, in order to assess and identify risks associated with a PLM solution (Bokinge, 2012).

## 3.2. Siemens Teamcenter Product Master Management

### 3.2.1. Siemens Teamcenter

Siemens offers a wide range of PLM software products aimed at improve companies' way of managing information related to a product throughout its entire lifecycle. One of the software products, Siemens Teamcenter, is the world's most used PLM software application (Siemens, 2015). Volvo Cars used Siemens Teamcenter when they were owned by Ford and have continued to use it ever since, yet owned by Geely since 2010.

Siemens together with Volvo Cars are currently developing a PDM system, Teamcenter Product Master Management (TcPMM), for managing part and product structure with the purpose of replacing the existing PDM system KDP in the long term. TcPMM is a new solution within Teamcenter that primarily addresses the product structure and BOM management area. TcPMM aims at managing the product master (BOM) effectively, from the creation of the product master content to the implementation in production. Siemens TcPMM is based on benchmark studies of large automotive companies in the field. By integrating the BOM product structure managed in KDP into Teamcenter, inconsistency between production BOM (KDP) and engineering BOM (Teamcenter) can be avoided and a one-to-one ratio between part information and documents can be managed and maintained.

Within TcPMM there is a Colour BOM solution for managing coloured parts and combination of colours. The information in the next section, *3.2.2 TcPMM and colours*, is collected from discussions with Mikael Gustavsson at Volvo Cars IT and Olle Hansing at Siemens, together with training material and instructions developed in conjunction with presentations and workshops used for Teamcenter 10.1 (Siemens PLM Software, 2014) and TcPMM 10.1.3 (Siemens PLM Software, 2015). The software solution is still under development and the following information is suggestions from Siemens in collaboration with Volvo Cars.

### 3.2.2. TcPMM and colours

The building blocks of a vehicle program in TcPMM, the engineering parts, can either be ordinary parts, Less Finish parts (Part Master) or Colour parts. These parts are released through an engineering work order (EWO). Less Finish parts are parts without any colour information, hence they do not have any finish colour. A Less Finish part can be permanently Less Finish, e.g. an engine where the colour information is irrelevant, it is then referred to as an ordinary part. A Less finish part can also be temporarily Less Finish, e.g. body parts that is yet to be painted and delivered in different colours. At the final stage when the Less Finish part is associated with a colour, it changes from being a Less Finish part to a Colour part. Colour parts are thus parts that have finish colours associated with them. A Less Finish part number together with a colour definition generates a coloured part. The Less Finish part's purpose is to indicate all technical specifications and it is used for procedural purposes. Less Finish parts can therefore be created early in the process, before colours and colour combinations are decided. The Less Finish part number does not represent an actual part that goes into the vehicle assembly, but instead the Colour part and the ordinary part are used in the vehicle assembly. Less Finish parts are developed by engineering department focusing on the functional aspects, and the colour appearance parameters are set by marketing and styling departments focusing on the surface appearance.

The transformation from Less Finish part to Colour part is done by applying a colour rule to a Less Finish part. A colour rule describes the colour appearance that will be applied to the referenced Less Finish part. The Colour part then inherits the design and engineering attributes from the Less Finish part. Besides this information the Colour part in TcPMM also carries the additional colour information, such as surface colour, texture and gloss. One can say that the colour appearance acts like a virtual master sample (physical definition) for the part. A Less Finish part associated with one colour is referred to as a single-coloured part (e.g. a bumper), and a Less Finish part associated with more than one colour, using a colour appearance group, is referred to as a multi-coloured part (e.g. a front seat or a complete interior). This is specified when the colour rule is created. An illustration of the engineering parts and colour appearance connection is shown in figure 2.

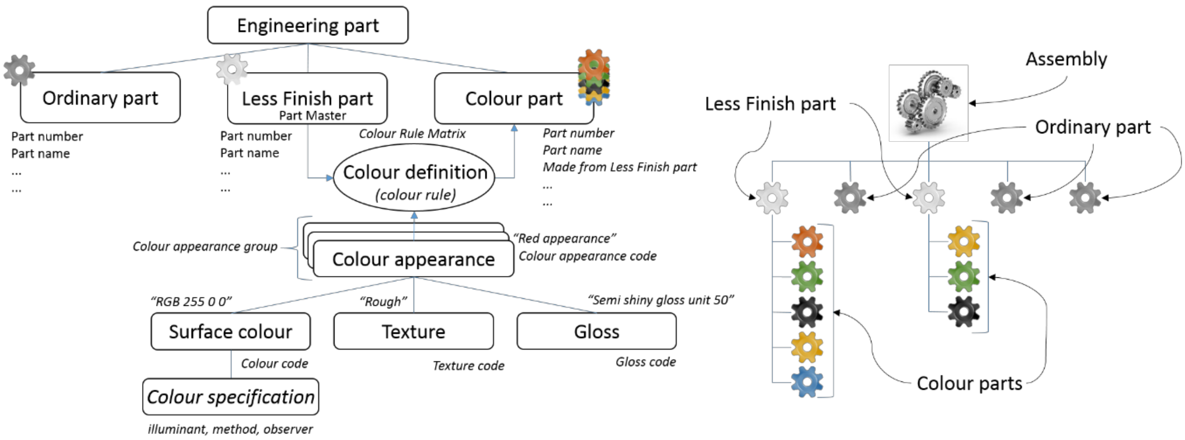



*Figure 2 – Engineering parts and colour appearance connection.*

A Line of Usage (LOU) describes under what conditions a part is used in a product and in what quantity, hence it specifies the usage criteria or conditions under which a part is included in the BOM for a product. A colour LOU is created from a Less Finish LOU and indicates usage of the part in the product and usage of the specific colour of the part. Colour rules, Colour parts and colour LOUs are created and managed in a colour rule matrix. Each colour rule generates a unique Colour part and colour LOU.

The basic steps for creating a Colour part in TcPMM are:

- Create and release a Less Finish part
- Create colour: create and manage a library of colour appearance elements (surface colour, texture and gloss) and colour rules
- Create and manage Colour parts and colour LOUs

Colours are defined by creating a colour appearance. The appearance of a coloured part (colour appearance code) is defined by creating three attributes; surface colour (with colour filling, e.g. in colour model RGB or CMYK), texture (e.g. rough or smooth) and gloss (e.g. shiny or matte). A colour specification is then created and connected to the colour filling. Colour specifications provide additional information used to standardize the observation conditions for coloured objects and includes values for illuminant, method of observation and the observer. The created colour appearance is a unique and standardised combination of surface colour, texture and gloss. As previously mentioned colour appearances can be grouped into a colour appearance group for parts or subassemblies with multiple colour appearances. The colour rules, which put colours to the Less Finish part and makes it a Colour part, are created in a colour rule matrix. Colour rules are set for the Less Finish part, which means that connections to the previously created colour appearances are established. When the rules are created and assigned to the colour appearances, Colour parts and colour LOUs can be created. Colour parts are created from each colour rule. The Colour part gets a number of attributes, among other things a part number, part name and made from part number which indicates inheritance to the Less Finish part (Part Master). Colour LOUs are also created from each colour rule. The colour LOU is created using the corresponding Less Finish LOU (target LOU) together with additional information and attributes. Figure 3, retrieved and redrawn from Siemens TcPMM training material, illustrates an example of the relation between a Less Finish part (Part Master), colour appearance and the colour rule matrix. In the example a Less Finish part is available in two colours (colour appearances), and two colour rules are set as a prerequisite for creating the Colour parts and colour LOUs. A matrix with checkboxes is used to control the parts, i.e. the colour rule applies for a certain model.

Less finish part

| Part | Ver | Part Name | LF/CL | Made from part | AUTH | Effectivity |
|---|---|---|---|---|---|---|
| GX_057 | V1 | Body Shell | LF | | GEC02 | 2015-EOT |

Colour

| Colour | Colour Name | R | G | B |
|---|---|---|---|---|
| CRD | Red | 255 | 0 | 0 |
| CGR | Green | 255 | 160 | 0 |

Colour specification

| Illuminant | Method | Observer | Specification |
|---|---|---|---|
| 155 | 15 | 10 | CSPEC1 |
| 155 | 15 | 10 | CSPEC2 |

Texture

| Texture | Texture Name |
|---|---|
| CANC | Ancona |
| CEMB | Emboss |

Gloss

| Gloss | Gloss Name |
|---|---|
| CMAT | Matte (GU50) |
| CGLS | GLOSS (GU70) |

Colour appearance

| Appearance | Colour | Texture | Gloss |
|---|---|---|---|
| VA_RDMA | CRD | ANC | MAT |
| VA_GRGE | CGR | EMB | GLS |

Colour Rule Matrix

| | | | | | | | | | Models | | Variable Conditions | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | BC | | |
| Rule | Ver | Zone | Part | Part Name | CAG | Surface DESG | AUTH | Effectivity | SDBS | SDSP | BSR | BSG | BSY |
| CR1 | V1 | EXT | GX_057 | Body Shell | CAGR | Body whole | GEC05 | 2015-EOT | ☐ | ☑ | ☑ | ☐ | ☐ |
| CR2 | V1 | EXT | GX_057 | Body Shell | CAGG | Body whole | GEC05 | 2015-EOT | ☑ | ☐ | ☐ | ☑ | ☐ |

*Figure 3 – Colour BOM redrawn* (Siemens PLM Software, 2015)

Further the Colour parts are aligned to the corresponding CAD models in Teamcenter, and solutions are created for the colour LOUs. CAD models are connected to both the Less Finish part and the Colour parts (colour injected CAD models). Solutions describe the use of a CAD model in a product with given effectivity and configuration condition, which means that positions are represented with solutions. A coloured engineering solve (BOM report) is used in order to review and verify the completeness of a product BOM, to see if the package and its content is ready to be released. A package is a container where the finalised work-in-progress (WIP) is added and organised together with other users' finalised WIP. In the coloured engineering solve details (Product type, Effectivity date, Model, Option String etc.) for a specific setup is entered and the colour LOUs and solutions appear in the BOM solve results, and the corresponding model in accurate colour appearance is visualised in the viewer. Figure 4 shows the colour BOM process flow retrieved and redrawn from Siemens TcPMM training material.

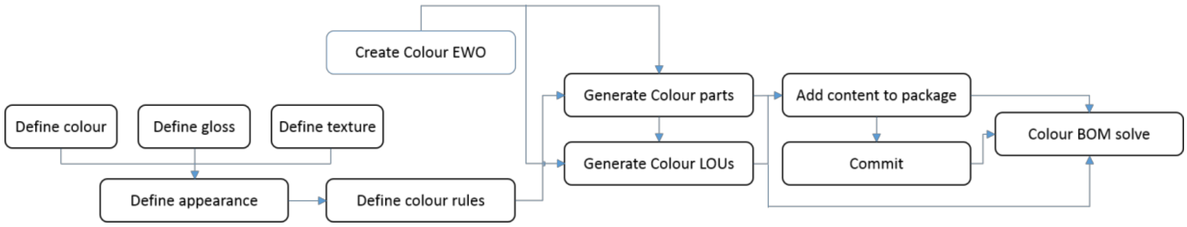


*Figure 4 – Colour BOM process flow redrawn* (Siemens PLM Software, 2015)

At Volvo Cars there is a request for visualising a complete vehicle, in Teamcenter Visualisation (TcVis), with parts in correct colours and surface materials according to a specific configuration. CAD models in the PLM system (Teamcenter) does not contain information about colours and surface materials, however for each part this information exists and is available through the product structure and master samples in Volvo Cars' existing PDM system KDP. In order to solve this problem information has to be merged from both of these sources to be able to make the connection between CAD model and accurate colour and surface material for the setup. Using two different information systems (KDP and Teamcenter) creates a challenge. The vision is to get the same functionality as the car configurator online in the early phases of the product development. By visualising different configurations and setups today's process quality could be improved and recourses needed could be minimised, as well as problems and errors in the product structure could be seen and avoided in early stages. A single source of information through Teamcenter (PMM and TcVis) might facilitate the way of managing colours and colour combinations, and also ensure a one-to-one ratio between part information and CAD models.

## 3.3. Summary of state of the art analysis

Large companies still use self-developed PDM systems with step-wise developed functionality, in order to meet future needs. The importance of a well-functioning and consistent product structure is stressed, to support product variety, reduce lead times and manage global production. Clear information management strategies are vital to fulfil the different departments' needs and requirements within the organisation. To become successful one has to find the balance between product variety and the internal complexity that it entails, especially in information management. The literature study showed that there are a lot of research and information about the need and request for and importance of well-functioning information management when it comes to product structure and product complexity. When it comes to product structure and colour management in PDM systems, very few and valuable research publications could be found. In research publications colours might have been neglected and just treated as any attribute.

The literature study also showed that there are a lot of publications about the trend and importance of product complexity and variety, and the need and request for managing customised and personalised products in PDM systems. Most of the companies within the automotive industry use self-developed PDM systems, which might mean that the product structuring and colour management is highly company-specific. However, that does not simply mean that their solutions differ from each other. Within the automotive industry confidentiality is vital. This may also lead to that this kind of information stays within the companies, which makes it even more difficult to find concrete details in how product structure and colour management in PDM systems is solved. There is a need for research in this area.

Although TcPMM is under development, it provides a clear way of managing colours and colour combinations, but the solution it is not complete, hence all parts are not covered yet. In order to draw additional conclusions one might have to study the colour management in several other PDM systems, especially PDM systems that are currently operating. However, a comparison between the colour management in TcPMM and the colour management in KDP at Volvo Cars is found in chapter *5.1. TcPMM in comparison to KDP*. The next chapter presents the findings from the colour management at Volvo Cars.

# 4. Findings

A large part of the project was about mapping the current situation. PLM development is a redesign process where mapping and clarifying is important in order to understand the current state and to facilitate when proposing recommendations of improvements (Malmqvist, 2014). The chapter starts with describing another recently implemented method of registering and managing coloured parts in KDP. It is followed by a section comprising a textual description of the theory behind the product structure and colour management with a colour system solution in KDP, followed by an applied example. A system modelling part describes the process in which the colour system is included, a process model, and an information model is also presented in order to demonstrate the relations in a diagram. It ends with a summary, which sums up and concludes the chapter.

## 4.1. Two working procedures when managing colours

Since recently there are two ways to register and manage coloured parts in KDP. Besides using the colour system, which is a solution for creating and managing coloured parts and colour combinations in KDP, there is also a manual way of doing it. It was decided to use the manual procedure for interior parts for the new platforms SPA (Scalable Product Architecture) for vehicle type 40 and 42, and for the CMA (Compact Modular Architecture) for vehicle type 27. For all external parts and interior parts prior to 40, 42 and 27 the colour system in KDP is still used.

The reason for introducing a manual procedure is because the colour system has become too complex and obscure. A very few people in the division of Product Documentation are familiar with and advanced users of the colour system and its components today, and have the ability to operate it properly. The decision was taken because the manager at the division of Product Documentation did not want to be dependent on only a few people and the risk of losing these people. More information and an analysis of these two working procedures is found in chapter *5.2. The different working procedures at Volvo Cars*. The following sections in this chapter describe and emphasise the colour system procedure, starting with some basic theory.

## 4.2. Colour management at Volvo Cars

### 4.2.1. Product structure

In Product Lifecycle Management the product structure organises all components that make up a product, which means that it defines the relation between e.g. product, assembly, subassembly and component. There are two general kinds of product structures, which both often are based on hierarchy; the Bill of Materials (BOM) and the CAD product structure. However, different product structures are used during the different phases of the product's lifecycle (Grieves, 2011). In KDP the BOM product structure is managed and the colour system in KDP manages the product structure of coloured parts and colours combinations in different interiors and exteriors.

#### 4.2.1.1. Product structure at Volvo Cars

The product structure within Volvo Cars is, as in general product structure, used to describe the content of the products. At the top level a product (a complete vehicle) is described by a product number, which is a string consisting of 34 digits followed by an option string describing additional options made to the setup. The product number is created when the customer has ordered the car at the retailer or online. The first 12 digits are referred to as the product number 12 and the complete product number is referred to as product number 34. See figure 5 for an example of the product number and its different parts for a Volvo V60, retrieved and redrawn from Volvo Cars Product Documentation training material.

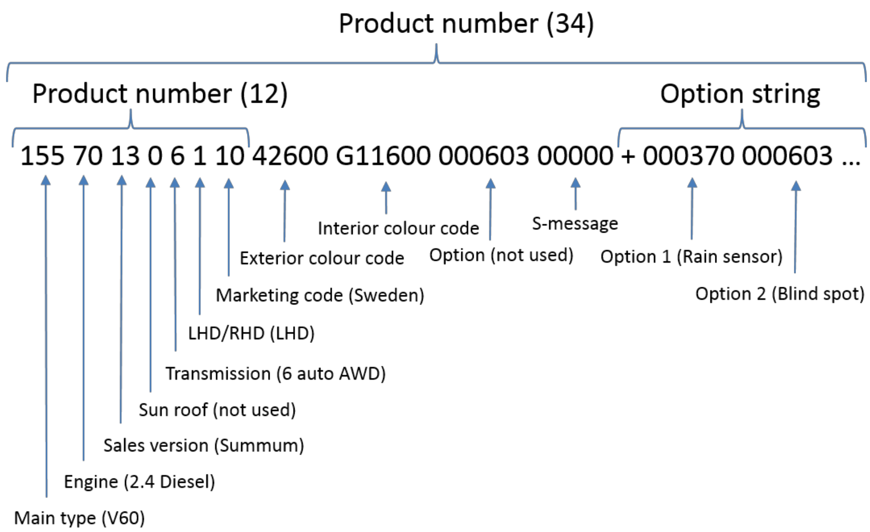



*Figure 5 – Product number for a Volvo V60* (Volvo Cars, 2015c)

The product number can be broken down into a set of variant designations. A product number consists of approximately 500 variant designations. The variant designation provides the relation between the product (product number) and the part (part number). See figure 6 for an example, retrieved and redrawn from Volvo Cars Product Documentation training material. The upper level is referred to as the Product specification (P-spec) and the lower as Part specification.

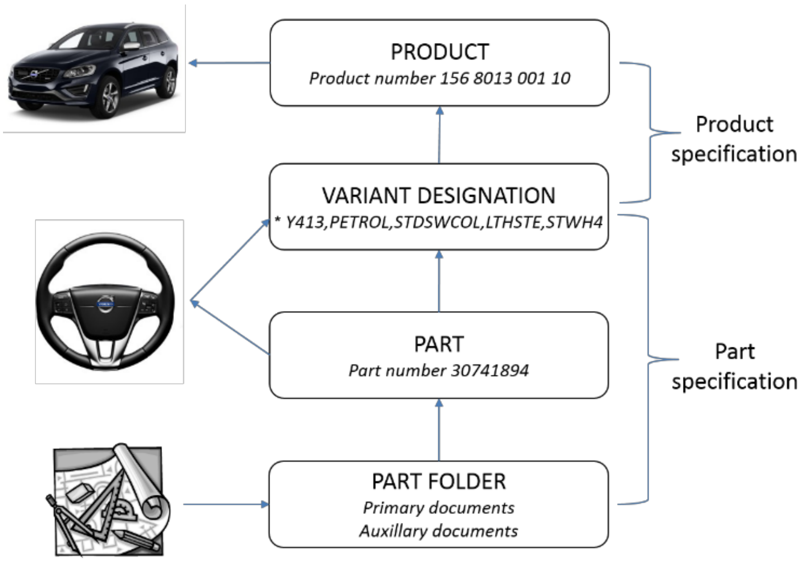



*Figure 6 – Product structure connections between product and part* (Volvo Cars, 2015c)

By using variant designations, the right parts are connected to right product numbers. Variant designations belong to variant families. One variant designation per variant family is connected to one or more type designations and the type designation group vehicle variants of the same type e.g. S80, S80L, V70 and XC70. One variant designation or variant combinations (two to five variant designations combined) are used in order to make the connection. The variant designations are listed in a variant string created from the product number. Variant packages are used to group variant designations in the Product specification. Each vehicle variant (e.g. V60) has a unique variant designation (V60 has Y352) and is part of a vehicle type (V60 belongs to type designation 78). The types in its turn belong to a product type, which has a product type number (type 78 belongs to product type 35). An illustration of this is shown in figure 7, retrieved and redrawn from Volvo Cars Product Documentation training material.

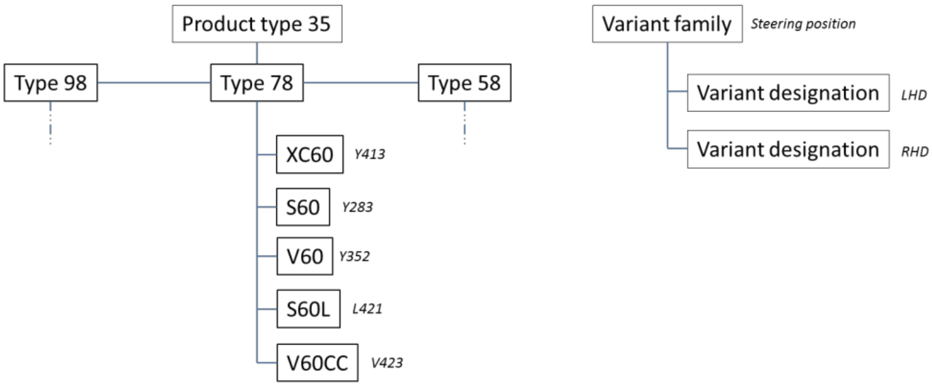



*Figure 7 – Product type 35 with type designations 98, 78 and 58 and vehicle variants (left). Variant family with variant designations (right). One variant designation per variant family is connected to one or more type designations* (Volvo Cars, 2015c)

In order to structure the product, the parts are grouped based on where they are placed and how they are assembled. The function group register describes the hierarchy, with groups and sub groups. The function groups can be divided into a few main groups. The product consists of approximately 270 function groups, which is the first level in the hierarchy. Each function group is divided into positions, POS, which is the next level in the hierarchy. At this level the main parts for each function group are listed. In each POS there is another level, POST, where the part numbers are organised within the POS. At the POST level the parts are referred to as so called delivery units, which mean parts or assemblies as they are delivered and assembled in the production line. However, in some cases delivery units can be a part of a delivery module. When the function group is broken down a list of different part numbers with variant designations are found on each level. Some parts may still be assemblies and can be broken down consecutively. The number of breakdown levels varies from part to part. See figure 8 for an illustration of the product structure hierarchy. The italic row that starts with an asterisk (*) is the variant string and contains the variant designations. Variant designation Y413 is XC60, and what COLOURED means will be discussed later in this chapter.

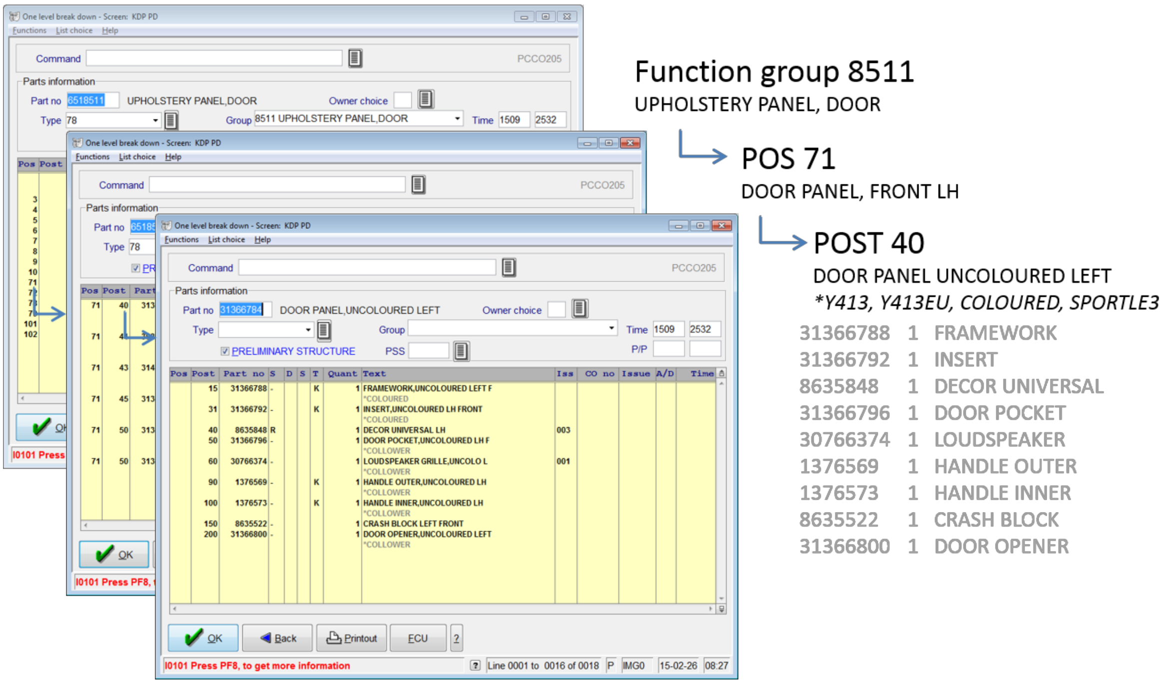



*Figure 8 – Product structure break down for a door panel in KDP (screens to the left) and in theory (right)* (Volvo Cars, 2015d)

#### *4.2.1.2. Change Order*

A Change Order (CO) is a document describing changes made to a specific product or part. It is a technical control document that is issued by each design responsible department and it is published in KDP by CO coordinators divided into function groups at the department of Product Documentation. The CO is the only document that describes and commands the introduction or change to a product or part. The product structure is created by connecting the part numbers to the accurate variant designation, using COs. COs from each department are assigned to the CO coordinator for the concerned function group. Figure 9 shows a CO for a door panel where variant designations for the parts are used for controlling the parts that are affected by the CO. The CO describes a change made to a door panel, where tape has been added on a framework, in order to improve the sound impression.

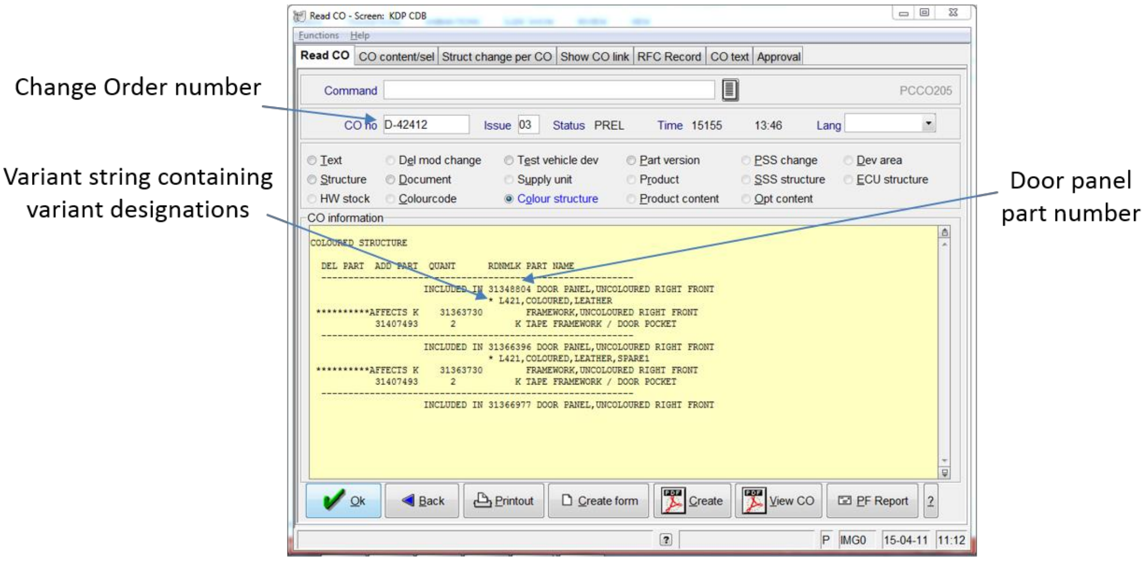



*Figure 9 – CO in KDP for a door panel with variant designations listed in the variant string* (Volvo Cars, 2015e)

The following information is controlled by a CO:

- Product structure; product and part specification
- Primary and auxiliary document
- Part version
- Torque for screw joints

The CO is provided for all units that are affected by its content. Its information forms the basis for e.g. suppliers, purchasing and for factory preparation and assembly plants.

### 4.2.2. KDP – Volvo Cars' PDM system

KDP is one of the main engineering tools that the PLM division is responsible for. KDP is an abbreviation for 'KonstruktionsData Personvagnar', which can be translated to 'Engineering Database Volvo Cars'. KDP is a self-developed system that handles information describing Volvo Cars' products, from a single component to a whole product such as a subassembly, an engine or a complete car. Hence KDP's main function is to manage the product structure – the Bill of Materials (BOM) product structure. However, documents defining and describing each part, such as drawings and CAD models, are also found in KDP, in the Part folder, but the structure is managed in other systems.

KDP is built up as a menu system, which means that it is divided into a number of submenus. The menus consist of screens, at the lowest level, which is a site where desired actions can be performed and the information can be found. From the main menu or the screen 'Search paths' submenus and screens can be derived. Screens are also searchable in KDP. Figure 10 shows the first screen in KDP, 'Search Paths', where submenus and screens can be found, and the most used screen 'Part number information', where information about parts can be found.

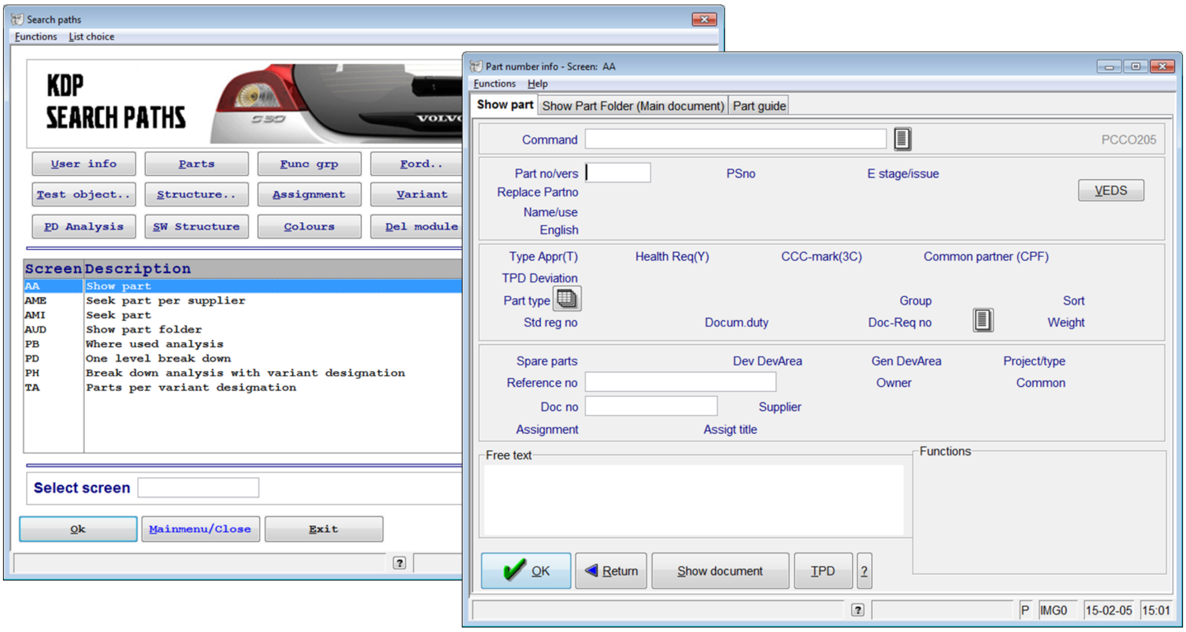



*Figure 10 – KDP's first screen 'Search paths' (left) and the screen 'Part number information' (right)* (Volvo Cars, 2015f)

All information created in KDP is constantly or at certain times distributed worldwide to other IT legacy systems in areas such as business administration, product development, purchasing and manufacturing. See figure 11 for an illustration of other legacy systems that uses information from KDP, retrieved from Volvo Cars Product Documentation training material. KDP is the heart of almost all IT systems within Volvo Cars.

The most frequently searched information areas in KDP are:

- Product types – Information about different products and type of products
- Product numbers – The 34 digit long number describing one unique car
- Variant designation – The description of a specific variant
- Part numbers – Information about the number that identifies a specific part
- Task structure –Task information broken down to engineering task for specific projects
- Change order – Document describing changes made to a specific product or part
- Product structure – Information about the relation between product and parts

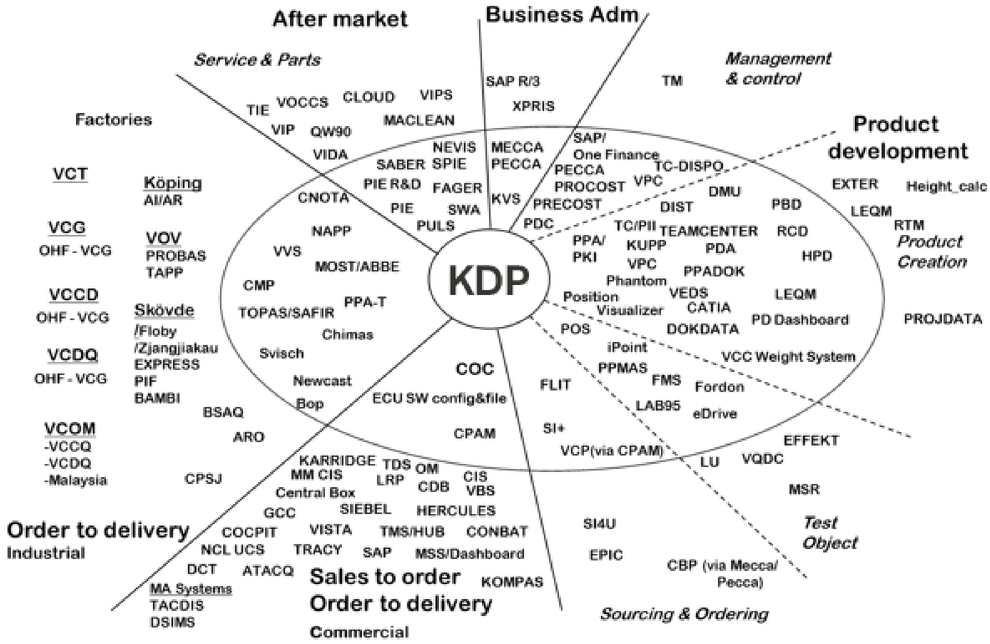



*Figure 11 – KDP legacy system overview* (Volvo Cars, 2015c)

## 4.2.3. Colour management in KDP

### *4.2.3.1. Colour coordination*

*Colour coordinated parts*, or simply *coloured parts*, are parts that are identical except that they differ in colour or material. The part can have different colours or materials, depending on the vehicle's interior or exterior, e.g. upholstery, carpets or sewing threads. Coloured parts are handled in a *colour system* in KDP. Colour system is the designation of a solution within KDP that creates and manages coloured parts for interiors and exteriors. In the late 1970s each part's drawing had a colour table, where all colours of the part were represented. Later this table became a colour document, which facilitated the work when adding, deleting and changing colours. A solution where the database creates and registers coloured part numbers, for one uncoloured part, was developed in KDP. The colour system assigns part numbers to the coloured parts (coloured part numbers) and handles colour combinations. When the colour system was introduced the philosophy was to let the ´machine´ create the coloured part numbers. The part numbers at Volvo Cars are so called non-intelligent part numbers, meaning that the part number itself does not provide any information about the part. The design engineer should only specify the structure, an uncoloured structure, once and it should be ease to create new colour combinations.

### *4.2.3.2. Colour management in KDP - Colour system*

The colour system's main elements are the *uncoloured product structure* and *colour tables*. An uncoloured product structure is a generic product structure where coloured parts and combinations are controlled. The uncoloured structure points to several alternatives. Therefore it is not specified which colour that is included. Instead there are *colour tables* which controls and combines the colours. For coloured parts the uncoloured structure is specified only once. Variant designations are used to specify what colour a certain part should have. The colour tables include colour codes, one superior (S-code) and one or more ingoing (I-code). The S-code contains I-codes and this table defines the interior or exterior of the vehicle. Figure 12 shows a theoretical example of the uncoloured structure and two colour tables.

| **1** | **Assembly 1, uncoloured** | **S00001** | **COLOUR1/COLOUR2** | **S00002** | **COLOUR1/COLOUR3** |
|---|---|---|---|---|---|
| 1 | Part 1, uncoloured<br>Variant designation a | I00001 | Colour 1<br>Variant designation a | I00001 | Colour 1<br>Variant designation a |
| 3 | Part 2, uncoloured<br>Variant designation b | I00002 | Colour 1<br>Variant designation b | I00003 | Colour 2<br>Variant designation b |
| 1 | Part 3, uncoloured<br>Variant designation a | I00003 | Colour 2<br>Variant designation c | I00004 | Colour 3<br>Variant designation c |
| 1 | Part 4, uncoloured<br>Variant designation c | | | | |

*Figure 12 – Uncoloured structure (left) and colour tables (middle and right).*

The S-codes together with the upholsteries are used to define the colour (theme) of the interior or exterior and the I-codes are used to define the colour for each part in the interior or exterior and is a part of the S-code. The variant designations that are used for controlling the I-codes are also found in the uncoloured structure. When there is a change in a part, it is done in the uncoloured part, and the information for the coloured parts are updated automatically. As previously mentioned the colour system automatically creates coloured part numbers and coloured structures for the uncoloured part.

Coloured parts that are assemblies, also referred to as 'coloured complete parts', with at least one underlying part and where ingoing parts are supplied as spare parts are connected to an uncoloured part and one or more S-codes. Hence, this coloured part can be included in one or more S-codes, thus in different interiors or exteriors. Coloured parts with no underlying structure, also referred to as 'coloured single parts', are connected to an uncoloured part and an I-code. When a new coloured part (an existing uncoloured part in a new colour or material) and/or a new colour combination (interior/exterior) is added, a new S-code and I-code has to be created. When a new uncoloured part is added, the structure (uncoloured structure) also has to be changed.

Master samples are divided into coloured and uncoloured master samples. Coloured master samples describe the appearance and surface structure of the part's colour or material physically and are stored at Volvo Cars for all coloured parts. A master sample shows and sets a particular requirement for the purpose of inspecting parts in that specific colour or material. It provides requirements for structure, pattern, colour and gloss of a surface, but not shape, size, thickness or similar. The uncoloured master samples do not describe the part physically, but is just for structure and administration in KDP. A coloured master sample is connected to a coloured part and an uncoloured master sample in KDP. For each coloured and uncoloured master sample there is a distinction between processed and unprocessed master samples. The majority of the coloured master samples are unprocessed, meaning that there should be no more treatment to the part. For parts that should be treated further processed master samples exist. In order to clarify the colour system in KDP a substantive example is provided in the next section, *4.3. Applied example – Colour management in KDP*.

## 4.3. Applied example – Colour management in KDP

An interior part, a door panel insert, used in today's Volvo cars is used in this example to demonstrate the uncoloured and coloured structure, colour tables with connections and relations between S-codes and I-codes, the elements in an interior matrix, and relations between different screens in KDP. In this example the interior is already decided and the product and part structure in KDP is already established. However, in section 3.3.2. Process models the process of how it is created, with roles, tasks, supporting documents and IT systems, is described.

### 4.3.1. Customer configuration

Suppose that the customer builds and orders a Volvo V60 using the car configuration online. As upholstery the customer chooses sport leather with black headlining when designing the interior, see figure 13. The product number is built up as the customer finishes the setup with additional options.

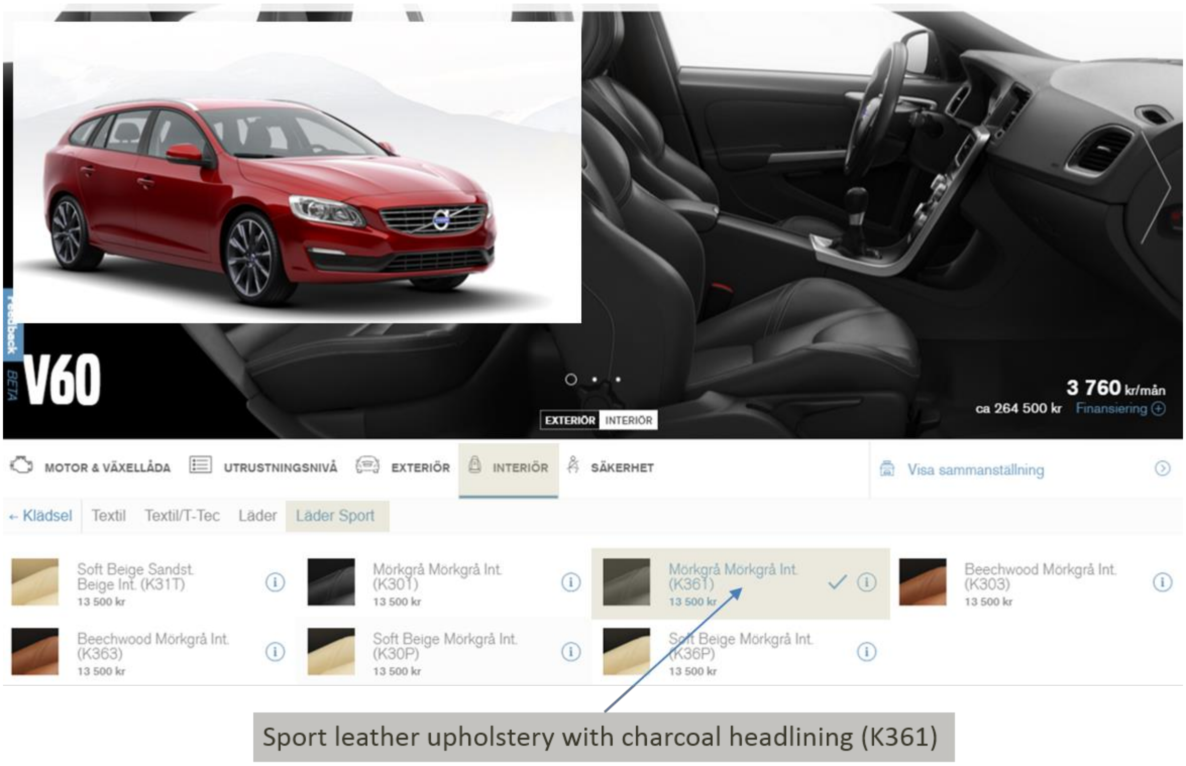
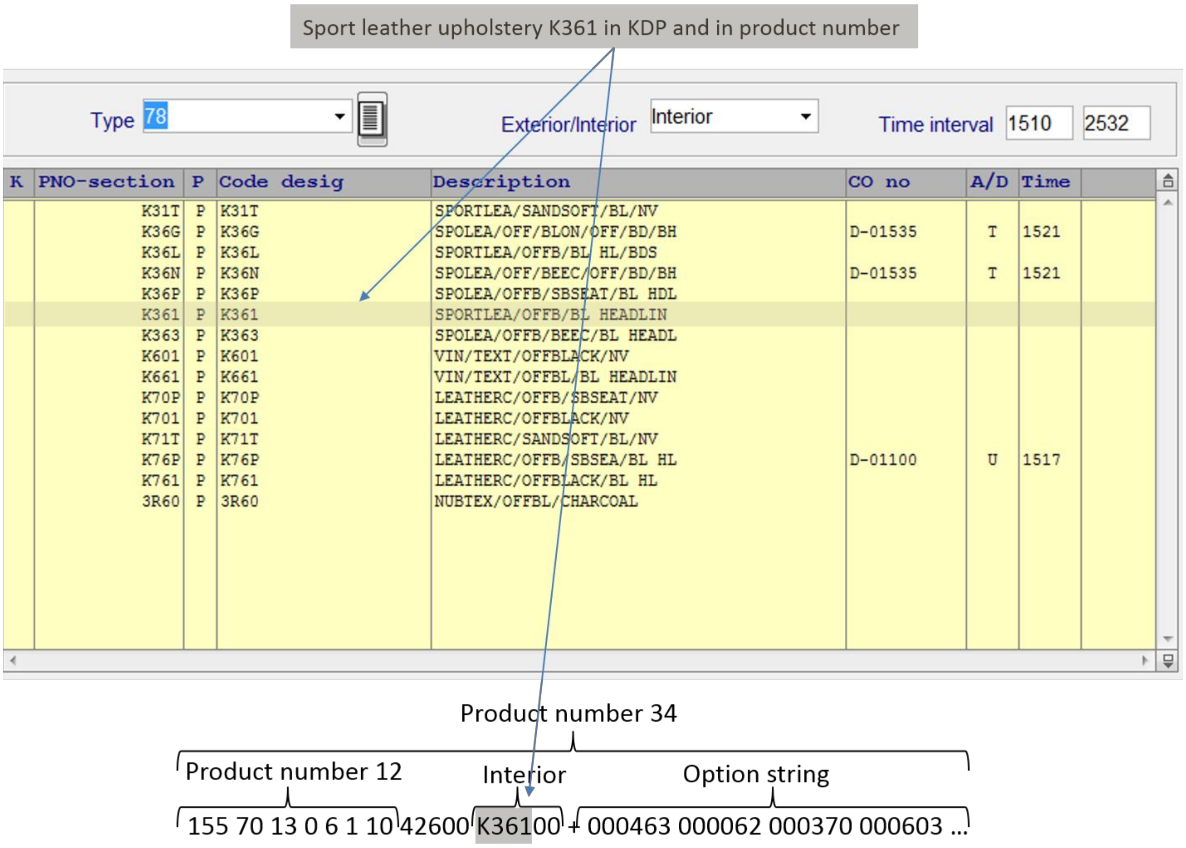



*Figure 13 – Customer car configuration online* (Volvo Cars, 2015g)

In KDP this upholstery has code designation K361, which is the same as in the product number for the interior (product number interior colour code), see figure 14. It is created and managed by the variant coordinators in the division of Product Documentation.



| K | PNO-section | P | Code desig | Description | CO no | A/D | Time |
|---|---|---|---|---|---|---|---|
| | K31T | P | K31T | SPORTLEA/SANDSOFT/BL/NV | | | |
| | K36G | P | K36G | SPOLEA/OFF/BLON/OFF/BD/BH | D-01535 | T | 1521 |
| | K36L | P | K36L | SPORTLEA/OFFB/BL HL/BDS | | | |
| | K36N | P | K36N | SPOLEA/OFF/BEEC/OFF/BD/BH | D-01535 | T | 1521 |
| | K36P | P | K36P | SPOLEA/OFFB/SBSEAT/BL HDL | | | |
| | K361 | P | K361 | SPORTLEA/OFFB/BL HEADLIN | | | |
| | K363 | P | K363 | SPOLEA/OFFB/BEEC/BL HEADL | | | |
| | K601 | P | K601 | VIN/TEXT/OFFBLACK/NV | | | |
| | K661 | P | K661 | VIN/TEXT/OFFBL/BL HEADLIN | | | |
| | K70P | P | K70P | LEATHERC/OFFB/SBSEAT/NV | | | |
| | K701 | P | K701 | LEATHERC/OFFBLACK/NV | | | |
| | K71T | P | K71T | LEATHERC/SANDSOFT/BL/NV | | | |
| | K76P | P | K76P | LEATHERC/OFFB/SBSEA/BL HL | D-01100 | U | 1517 |
| | K761 | P | K761 | LEATHERC/OFFBLACK/BL HL | | | |
| | 3R60 | P | 3R60 | NUBTEX/OFFBL/CHARCOAL | | | |



*Figure 14 – Sport leather black headlining upholstery interior code in KDP (top) and in product number (bottom)* (Volvo Cars, 2015h)

### 4.3.2. Interior matrix and uncoloured structure

An interior matrix is an Excel document that specifies trim levels (also known as grades or option packages) for upholstery in the different interior variants and is used in the division of Product Documentation and forms the basis for the product and part structure. Figure 15 shows the interior matrix for a Volvo V60. There are two main categories of interiors to choose from; Antracite Black and Sandstone Beige. For each of them a set of upholsteries are available. The interiors' different parts are displayed in the rows. The interior part, the door panel insert, which occurs in different variants depending on upholstery, is used to describe how colours are controlled in the colour system in this example. The different upholsteries can be found in the middle rows of the matrix, hence the sport leather upholsteries are found here. For the customer's setup the chosen upholstery is 'Off Black K361', which gives a door panel insert in 'Off Black'. The X in the matrix indicates that the option is not available. There is e.g. only one type of sport leather R-design available (Charcoal solid Offblack KT60).

Door panel inserts

Upholstery colours and materials

| Name Interior | Antracite Black | | | | | | | | | Sandstone Beige |
|---|---|---|---|---|---|---|---|---|---|---|
| Upper part of dashboard | Off Black | | | | | | | | | Off Black |
| Lower part of dashboard | Off Black | | | | | | | | | Soft Beige |
| Tunnel | | | | | | | | | | |
| Door Panel | | | | | | | | | | |
| Door Panel Inserts | Off Black | Off Black | Soft Beige | Soft Beige | Steel Grey | Steel Grey | Beechwood | Beechwwod | Charcoal solid | Soft Beige |
| Tunnel armrest | Off Black | | | | | | | | | Soft Beige |
| Base carpets luggage | Off Black | | | | | | | | | Mocca |
| Base carpets cupè | Off Black | | | | | | | | | Mocca |
| Inlay carpets (floor mats) | Off Black | | | | | | | | | Mocca |
| Headlining | Quartz | Charcoal | Soft Beige | Charcoal | Quartz | Charcoal | Quartz | Charcoal | Charcoal solid | Soft Beige |
| Full Textile (TEXTILE) | Charcoal K001 | X | X | X | X | X | X | X | X | X |
| Dynamic (VIN/TEXT) | Charcoal / Off Black K601 | Charcoal / Off Black K661 | X | X | X | X | X | X | X | X |
| LeatherC t 13w26 (LEATHERC) | Off Black K701 | Off Black K761 | Soft Beige K70P | Soft Beige K76P | X | X | X | X | X | Soft Beige K712 |
| Leather (LEATHER) | Off Black K101 | Off Black K161 | Soft Beige K10P | Soft Beige K16P | X | X | X | X | X | Soft Beige K112 |
| Leather Sport (SPORTLE3) | Off Black K301 | Off Black K361 | Soft Beige K30P | Soft Beige K36P | Steel Grey / Off Black K30R | Steel Grey / Off Black K36R | Beechwood / Off Black K303 | Beechwood / Off Black K363 | X | Soft Beige K312 |
| Leather R-Design (SPORTLE4) | X | X | X | X | X | X | X | X | Charcoal solid Offblack KT60 | X |
| Leather R-Design (NUBLEA2) | X | X | X | X | X | X | X | X | Offblack KR60 | X |
| Colour variant | OFFBLACC | OFFBHLIN | OFFBSBE4 | OFFBSOB5 | OFBSGREY | OFBSGRE2 | OFFBBEEC | OFFBBEE3 | OFFCHA | SANDSOBL |
| S-kod | S00297 | S00352 | S00349 | S00359 | S00343 | S00367 | S00300 | S00368 | S00361 | S00334 |
| Variant | OFFB | | | | | | | | | SAND |

*Figure 15 – Sport leather upholstery 'Off Black K361' and door panel insert 'Off Black' in the interior matrix* (Volvo Cars, 2015i)

The door panel insert is a part of the door panel. The insert consist of a framework, a piece of vinyl and two sewing threads; one joining and one decorative, see figure 16.

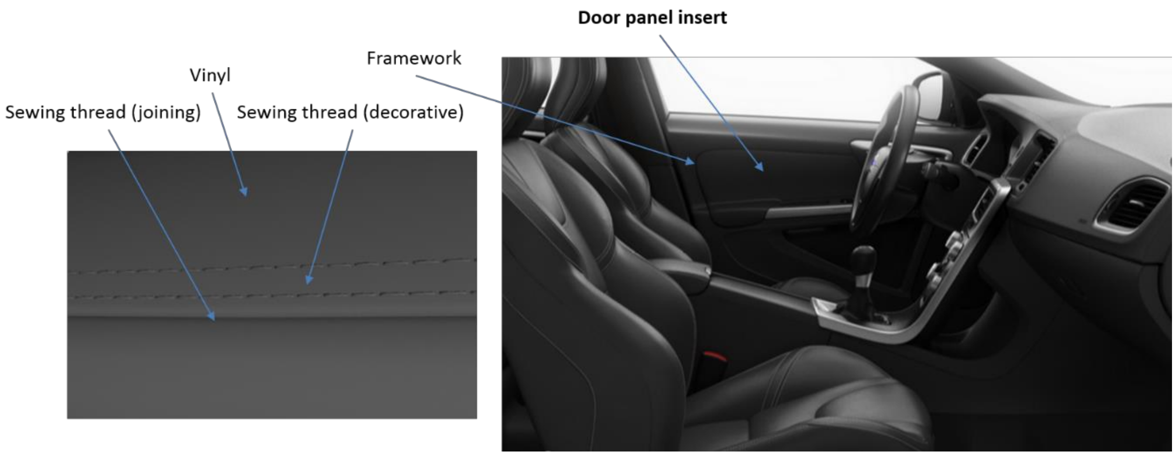



*Figure 16 – The door panel insert's parts (left)* (Wikenmalm, 2015) *and the door panel insert in its context, the interior (right)* (Volvo Cars, 2015g)

Figure 17 shows what the door panel looks like in the part list in KDP. This screen in KDP and the following KDP screens used in this example are the result from the created product and part specification managed by the CO coordinators and variant coordinators in the division of Product Documentation. Different variants of the door panel are presented as delivery units. A set of delivery units may belong to a delivery module, depending on complexity. Delivery units or delivery modules are parts or assemblies as they are delivered and assembled in the production line. The variant string that starts with an asterisk (*) contains variant designations, which provide the relation between the product and the part. In the figure this indicates an uncoloured door panel for a V60 (Y352) with sport leather upholstery (SPORTLE3).

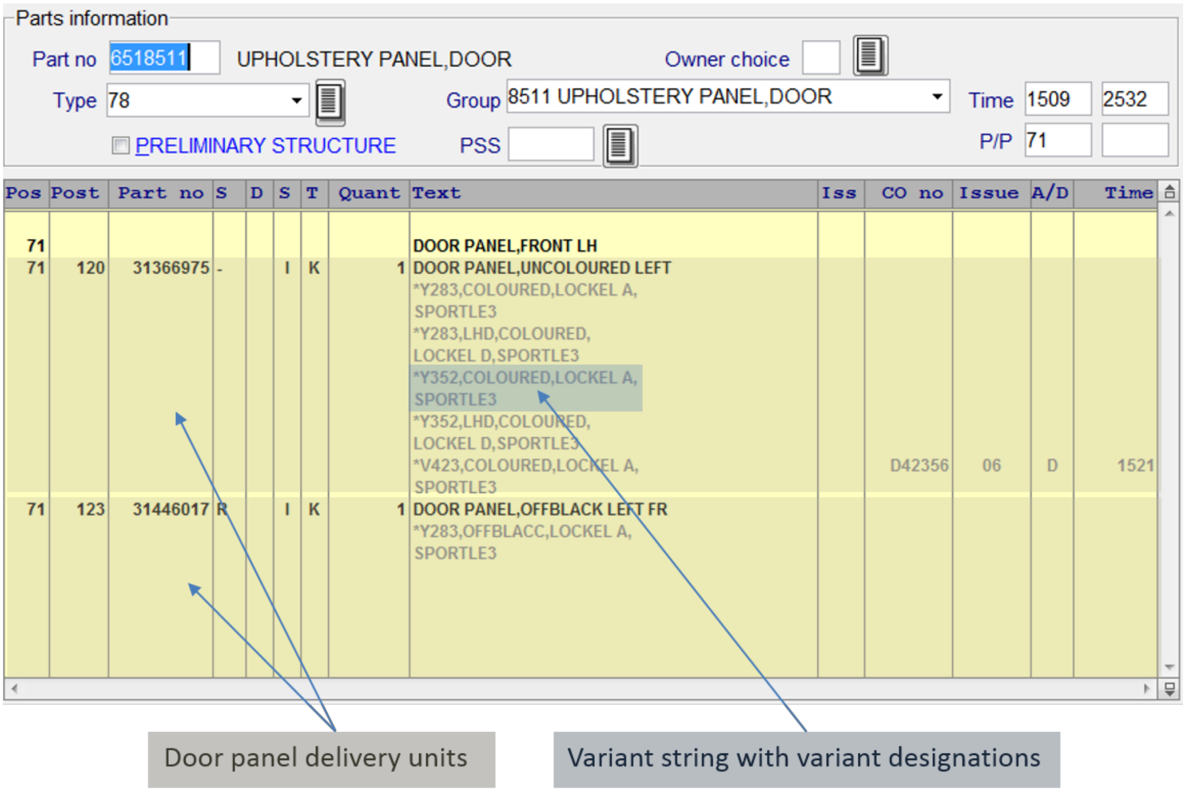



*Figure 17 – Delivery units for a door panel* (Volvo Cars, 2015d)

A breakdown view of the uncoloured structure for the door panel delivery unit with part number 31366975 is shown in figure 18. The door panel consists of a number of parts and subassemblies. The door panel's insert is an assembly (indicated by the K = complete) and consist of one subassembly and one part. Assemblies consisting of parts that are colour coordinated are specified with the variant designation COLOURED, which could be seen in the variant string for the door panel and the door panel insert. Colour coordinated parts are parts that have different colours depending on the vehicles interior. The insert consist of a piece of vinyl which is specified with the variant designation COLSEAT7, and sewing threads for a seam specified with COLSEW6 and COLTHR14, and a framework which is not colour coordinated.

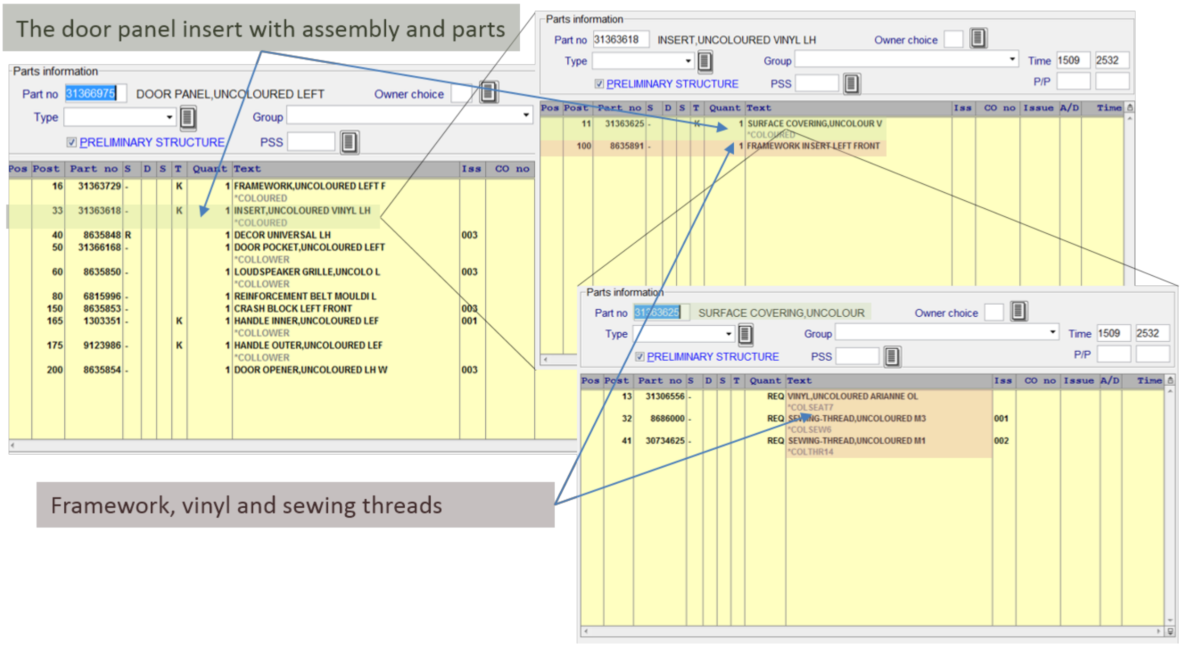



*Figure 18 – Uncoloured structure for the door panel delivery unit (left) and the door panel's insert (top right)* (Volvo Cars, 2015d)

### 4.3.3. Colour tables

Figure 19 shows two other screens in KDP, two different S-codes in which the uncoloured structure for the door panel's insert refers to and the variant designations are found. If we look at the two different sewing threads we can see that the first sewing thread with variant designation COLSEW6 is either 'off black', with the I-code I00039 in S00352 (the customer's configuration), or 'sandstone beige', with the I-code I00201 in another S-code S00359, which is used for a number of soft beige upholsteries. The second sewing thread with variant designation COLTHR14 is either 'off black', in S00352 as well, or 'light soft beige', in the other. In S00359 it has I-code I00200, which occurs several times. The difference lies in the variant designation, i.e. the connection to the structures, in which the S-code is used.

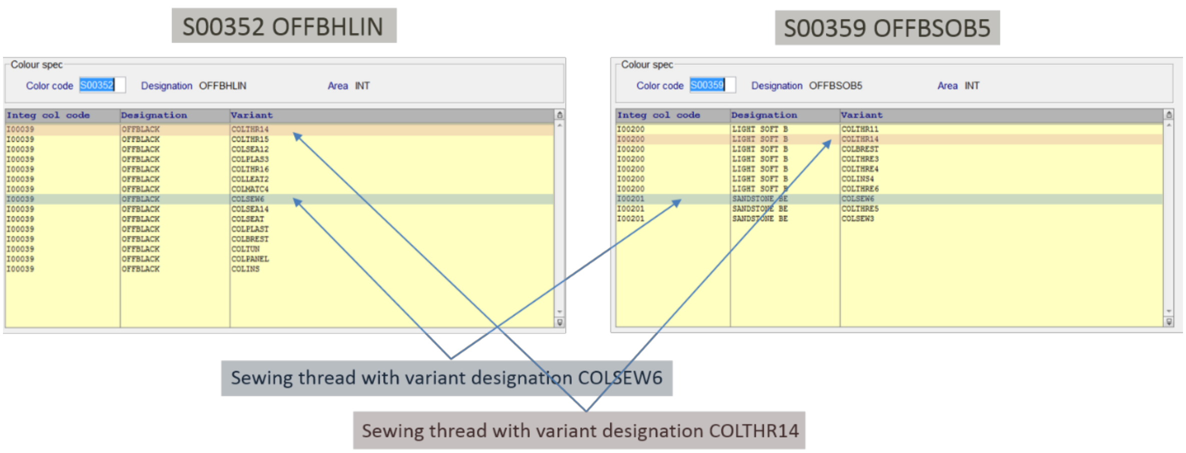



*Figure 19 – Content of S-codes, also referred to as colour tables for S00352 and S00359* (Volvo Cars, 2015j)

If we look back at the interior matrix, see figure 20, the previously mentioned S-codes S00352 and S00359 are found in the third and fifth column. The door panel insert is found in row six, and further down the sport leather upholsteries (SPORTLE3) including the customer's configuration 'Off Black K361' is found as well. The door panel insert for the other S-code S00359 is 'Soft Beige' because of the 'Soft Beige' upholstery and, as was seen in the colour table, the sewing threads in this insert are 'Light Soft Beige' and Sandstone Beige'.

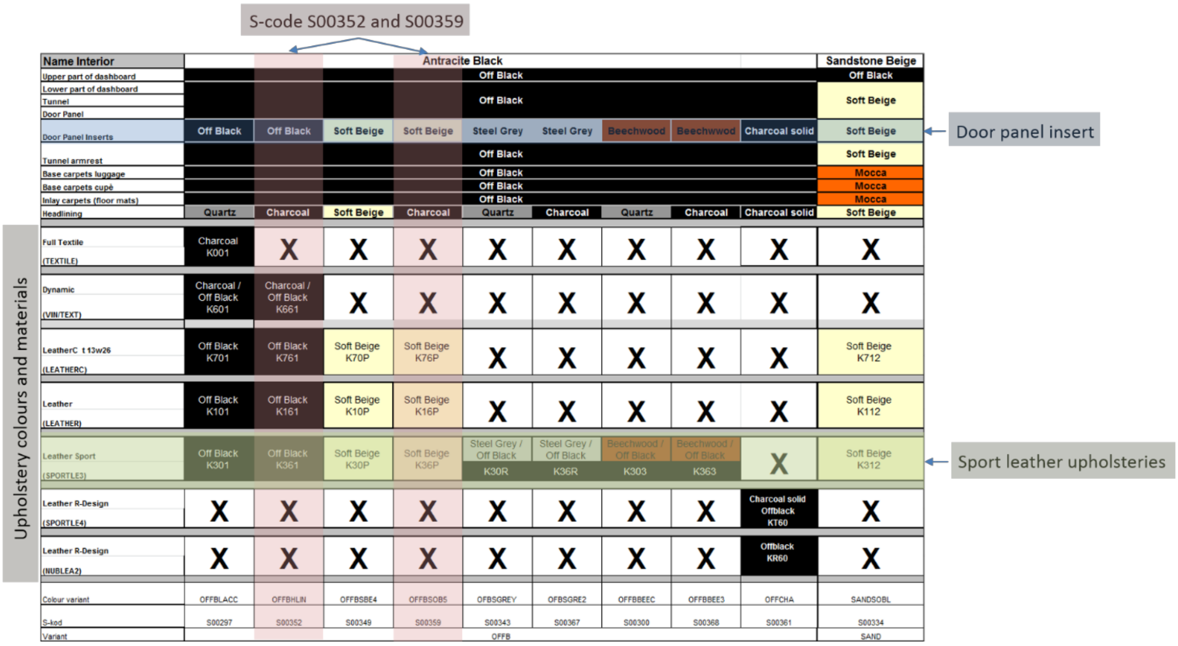


*Figure 20 – S00352 and S00359 in the interior matrix* (Volvo Cars, 2015i)

## 4.3.4. Coloured structure and coloured part numbers

Earlier the uncoloured structure for the door panel was presented, which is a generic one where it is not directly specified which colour that is included. Figure 21 shows a breakdown view of the coloured structure for a door panel delivery unit that is a part of the previously mentioned S-code S00352 OFFBHLIN, the customer's configuration. Coloured structures together with coloured part numbers are created automatically by the colour system, and is displayed in the CO. However, in this case the coloured structure is also showed in the part list. The process of how this is done is described in chapter 3.3.1.3. Process model – Colour system. From the variant string variant designation OFFBHLIN is found. At the lowest level for the insert the two sewing threads, which in this case are 'Off Black', are found. Although both of these are 'Off Black' they are not the same, since one is a joining thread and one is decorative (different thicknesses).

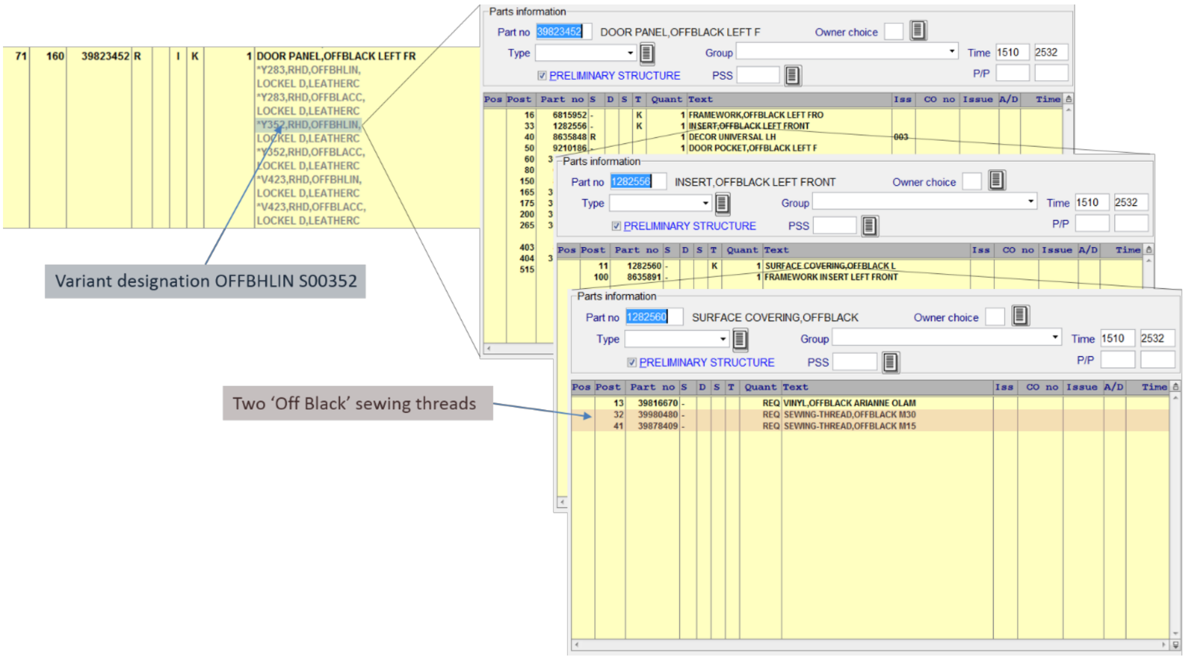



*Figure 21 – Coloured structure for an 'Off Black' door panel in S00352 OFFBHLIN, the customer's configuration* (Volvo Cars, 2015d)

As previously mentioned the colour system creates coloured part numbers for the uncoloured part. Figure 22 shows coloured parts connected to the uncoloured door panel's insert. Coloured parts that are assemblies, also referred to as coloured complete parts (K), with at least one underlying part and where ingoing parts are supplied as spare parts are connected to an uncoloured part and one or more S-codes. The insert occurs in a set of variants, each one belonging to one or more interiors (S-code).

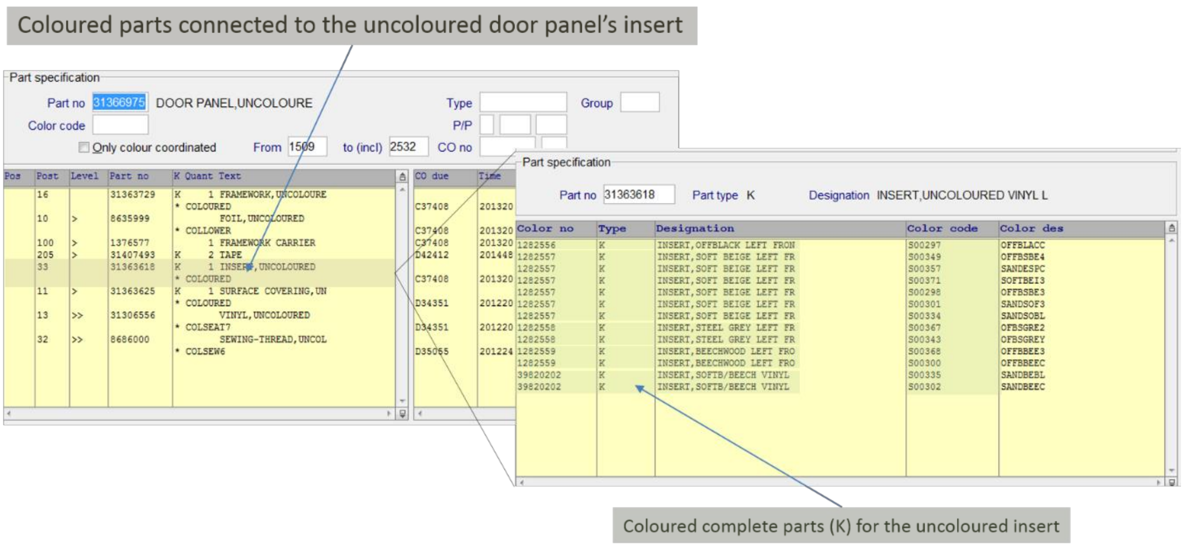



*Figure 22 - Coloured parts connected to the uncoloured door panel insert* (Volvo Cars, 2015k)

Figure 23 shows coloured parts connected to the uncoloured door panel insert's sewing thread. Coloured parts with no underlying structure, also referred to as coloured single parts (D), are connected to an uncoloured part and an I-code. The sewing thread occurs in a set of variants, each one connected to one I-code. Here the coloured part number for the ‘Off Black’ sewing thread (with I-code I00039, used in S00352) is found.

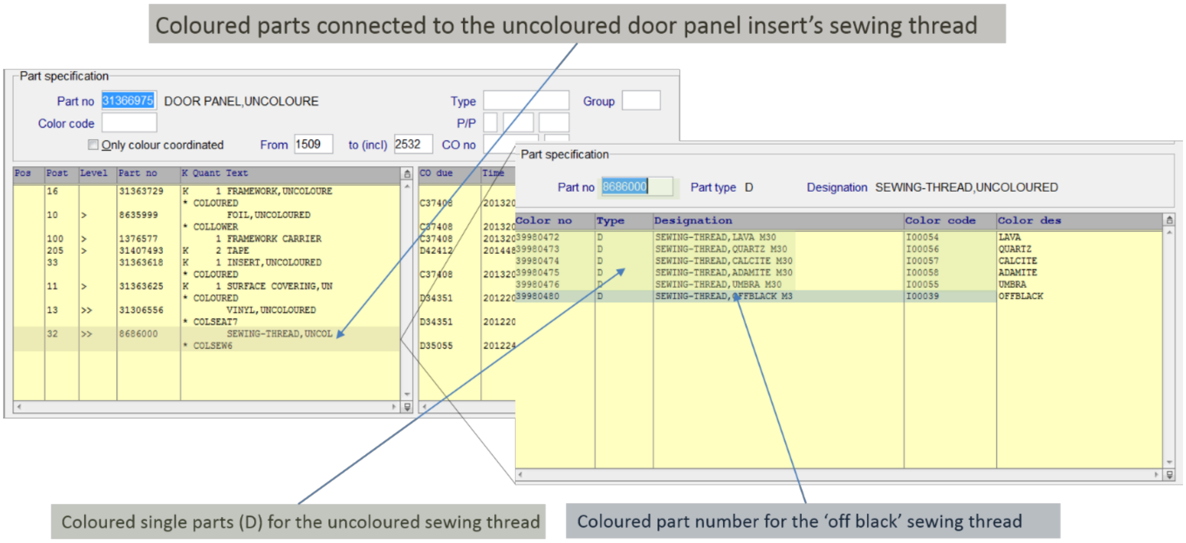



*Figure 23 - Coloured parts connected to the uncoloured door panel insert’s sewing thread* (Volvo Cars, 2015k)

### 4.3.5. Coloured and uncoloured master samples

To each I-code there is at least one coloured master sample connected, which in its turn is connected to an uncoloured master sample, see figure 24. The uncoloured master sample for a number of sewing threads and the coloured master sample for I00039 is shown here. This coloured master sample is a physical representation of the ‘Off Black’ decorative sewing thread used in the door panel insert for the customer’s configuration.

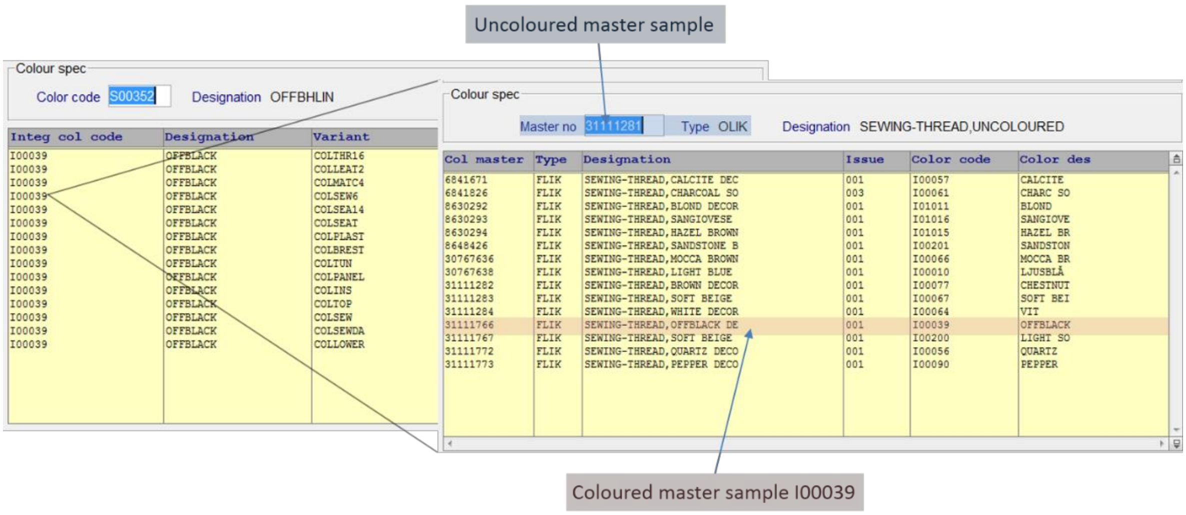
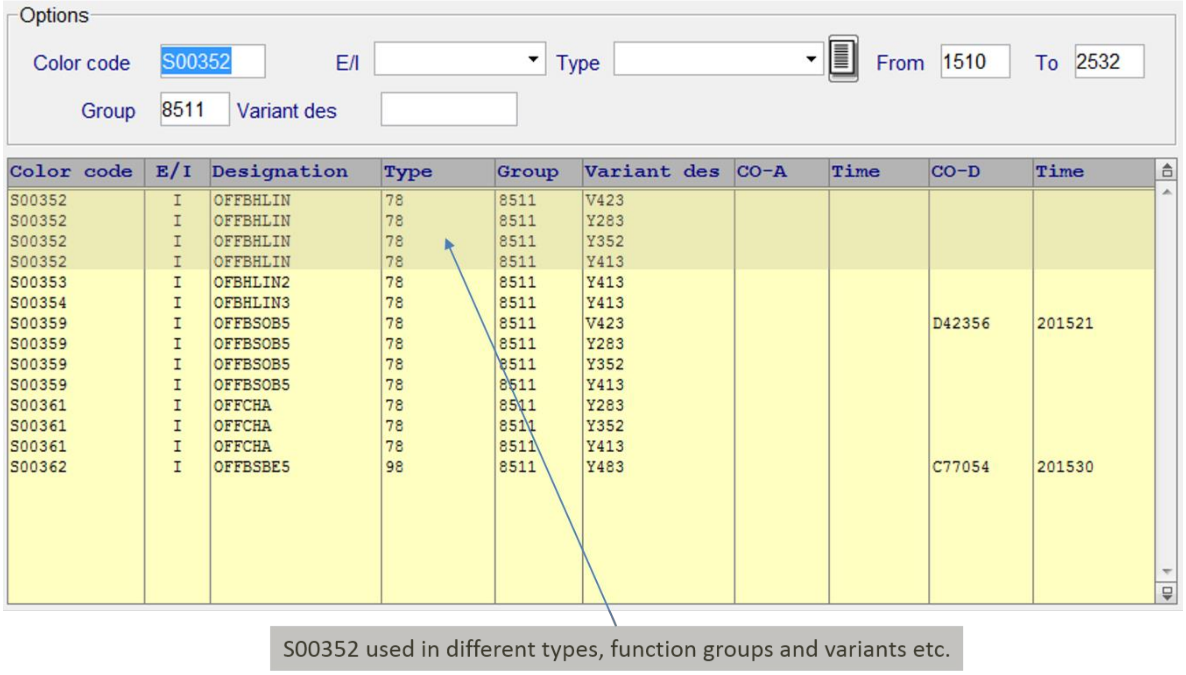



*Figure 24 – Uncoloured and coloured master samples* (Volvo Cars, 2015l)

Figure 25 shows a screen where more information about the S-codes, in this case the previously mentioned S00352, is found. The screen lists S-codes with designations, type designations, function groups, variant designations and COs with time that adds or deletes the colour code. S00352 is used for V60CC (V423), S60 (Y283), V60 (Y352) and XC60 (Y413). Group 8511 is the function group for door panel upholstery.




| Color code | E/I | Designation | Type | Group | Variant des | CO-A | Time | CO-D | Time |
|---|---|---|---|---|---|---|---|---|---|
| S00352 | I | OFFBHLIN | 78 | 8511 | V423 | | | | |
| S00352 | I | OFFBHLIN | 78 | 8511 | Y283 | | | | |
| S00352 | I | OFFBHLIN | 78 | 8511 | Y352 | | | | |
| S00352 | I | OFFBHLIN | 78 | 8511 | Y413 | | | | |
| S00353 | I | OFBHLIN2 | 78 | 8511 | Y413 | | | | |
| S00354 | I | OFBHLIN3 | 78 | 8511 | Y413 | | | | |
| S00359 | I | OFFBSOB5 | 78 | 8511 | V423 | | | D42356 | 201521 |
| S00359 | I | OFFBSOB5 | 78 | 8511 | Y283 | | | | |
| S00359 | I | OFFBSOB5 | 78 | 8511 | Y352 | | | | |
| S00359 | I | OFFBSOB5 | 78 | 8511 | Y413 | | | | |
| S00361 | I | OFFCHA | 78 | 8511 | Y283 | | | | |
| S00361 | I | OFFCHA | 78 | 8511 | Y352 | | | | |
| S00361 | I | OFFCHA | 78 | 8511 | Y413 | | | | |
| S00362 | I | OFFBSBE5 | 98 | 8511 | Y483 | | | C77054 | 201530 |

*Figure 25 – Colour code information* (Volvo Cars, 2015m)

### 4.3.6. Summary of applied example

This example is used to demonstrate the colour management in KDP using an existing part, a door panel insert. It describes what the part looks like in KDP and how everything is interlinked when a customer orders a new car. In this example the interior is already decided and the structure in KDP is already set. The example is a part of the mapping of the current situation and gives a basic understanding in colour management in KDP for further reading. Chapter *4.4.3. Process model – Create part specification* presents a process model of the colour system and describes how the uncoloured and coloured structure are created including among others where and how S-codes and I-codes are created, variant designations are registered and connections are made. The process model also describes where and how master samples are registered and connections are made.

## 4.4. Colour management process model

This chapter presents a process model section describing the approach when creating an interior or exterior for colour coordinated parts, in the product development and creation phase, with the product and part structure and the colour system in focus. The approach and process of how a part, like the door panel insert in the example, is thus described. The process model consists of an overview process flowchart, colour management overview (P.1), which includes two detailed process flowcharts describing two sub processes; Creating Product specification (P1.1) and Creating Part specification (P1.2). The chapter also includes an information model for a part presented in a class diagram.

### 4.4.1. Process model – Colour management overview (P1)

The first step in the process is to decide on interior or exterior for the vehicle, which forms the basis for the variant coordinators and CO coordinators in the division of Product

Documentation, in order to execute what is decided and create the product and part structure using the colour system. Product governance process, Market Specification details and interior matrix details are inputs and from these a detailed description of the product is derived in terms of Vehicle Binder, VB, and Market Specification including the interior matrix.

The variant coordinators use a number of documents in an iterative process as documents are continuously updated in order to create the Product specification. It involves among other things creation of variants, variant packages, codes, variant conditions and product numbers. This process is broken down further and its different parts are described in detail in *4.4.2. Process model - Create Product specification (P1.1).*

In the next step the Part specification is created, which is done by the CO coordinators who execute the colour system tasks in the application KDP. This process is a central part of the colour management and it is done only for coloured parts. The CO coordinators use the colour system in KDP to among other things create S-codes and I-codes, register master samples, make connections and create the coloured and uncoloured structure according to the colour system process. This process is broken down further and its different parts in terms of tasks are described in detail in *4.4.3. Process model – Create Part specification (P1.2)*.

In addition to this documents in Teamcenter have to be approved and published and thereafter the part folder has to be published by the design engineer and task leader before the CO can be published by the CO coordinator. The part folder contains primary and auxiliary documents, such as drawings and CAD models, and defines the part version. When the required prerequisites are fulfilled and the CO is published it becomes official and available for downstream system. About 100 different systems are affected by a published CO. The most significant ones are Hercules, which is a Sales and Supply Planning System used to present production prognosis, and SI+, which is a Purchasing System that keeps track of the need for parts and material to the plants. In addition to this the CO and its content becomes legally binding when published. See figure 26 for an illustration of the overview process model. For a larger size, see appendix C.

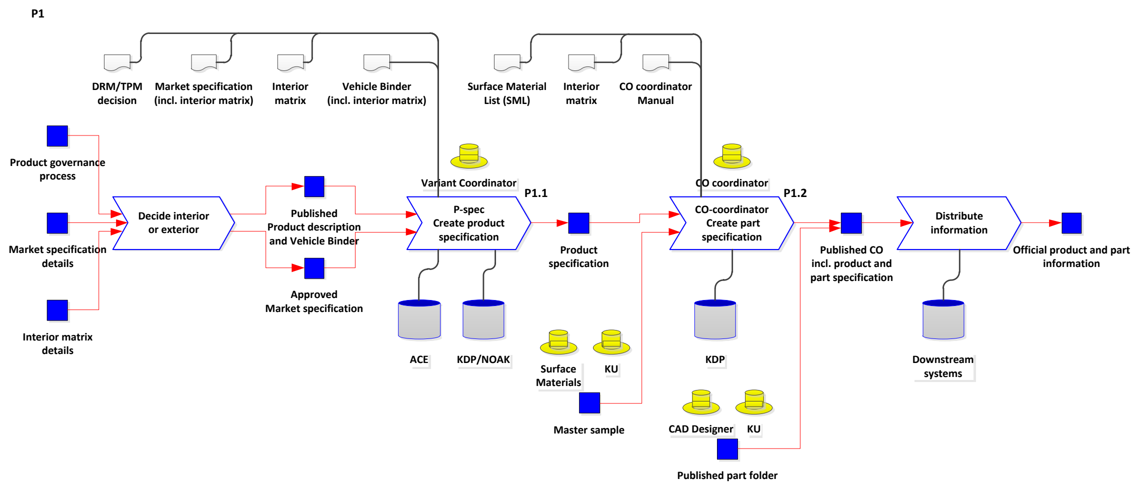



*Figure 26 – Process model – Colour management overview (P1)*

### 4.4.2. Process model – Create Product specification (P1.1)

The variant coordinators create variants, variant packages, codes, variant conditions and product numbers (P1.1.1). For new interior and exterior codes, the variant coordinators also create variants, variant packages, codes and variant conditions (P1.1.2).

Variant designations are the link between the product number and the part, and variant conditions are used to define and control these. Variant conditions are rules for what variant designation per variant family a product number should have. Variant designations are registered in the application ACE (Authorisation Change Engineering), which is an application used for managing variants, then they are visual in KDP. Variant designations are registered per vehicle type and can be searchable via the variant designation itself or variant family. Variant families group variant designations. Variant packages group variants from different variant families. The interior code is a part of the product number and describes the interior including the upholstery for the vehicle. The exterior code is also a part of the product number and defines the colour of the vehicle. The product number is a numerical description of a vehicle.

The Vehicle Binder, VB, is a document that defines the content of control models. A control model is a product number that indicates cost, and is followed up by the variant coordinators if any changes are made. In the VB, the control models are general, i.e. no options are included. The VB is only used for new car programs and includes trim levels, powertrain, exterior, interior, chassis, breaks, wheels, tyres, infotainment and other functions and features that make up a complete vehicle, and it also includes the interior matrix. After these actions an initial Product specification, P-spec, is formed. The VB is then continuously refined, and the P-spec is then updated in an iterative process (P1.1.5), which is required due to the recurring updates of the VB.

Later in the project, a Market Specification is released. The Market Specification is a document that defines the content of all product numbers for all markets. When the first issue is released, the variant coordinators do not use the VB anymore. The Market

Specification is also continuously refined, and the P-spec is updated. Decisions at Technical Program meeting, TPM, and Design Review meeting, DRM, are also affecting the P-spec along the way. The application ACE and screens in KDP related to Product specification, also referred to as KDP/NOAK, are used as supporting IT systems throughout the process. Figure 27 illustrates the process model for creating the Product specification (P1.1). For a larger size, see appendix D.

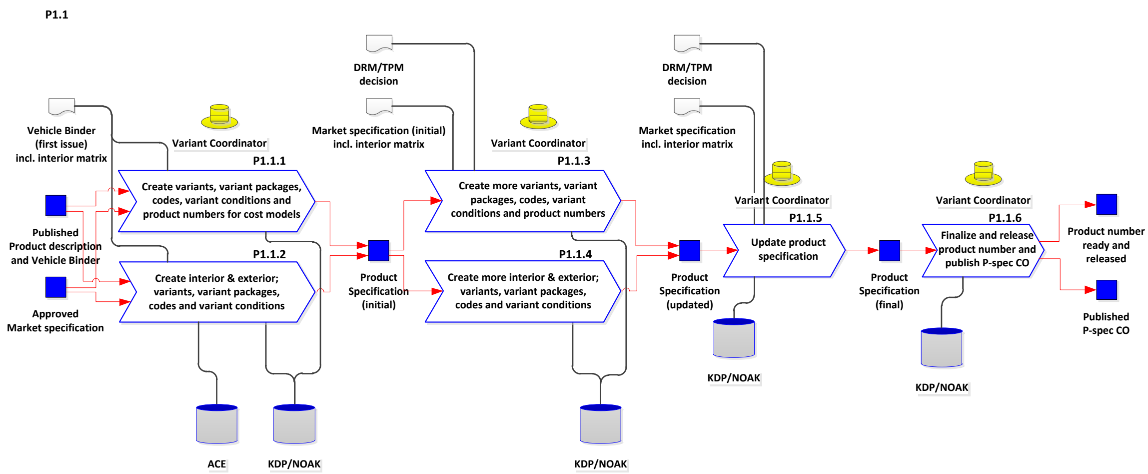


*Figure 27 – Process model – Create Product specification (P1.1)*

### 4.4.3. Process model – Create Part specification (P1.2)

In this process the most significant parts of the colour management are executed. Depending on what action that is going to be performed different paths through the create part specification process are taken. This section describes all tasks performed throughout the process. However, the most frequent action takes place when a new interior for an existing vehicle is decided, i.e. a new S-code and I-codes are needed.

Starting with the top left sub process, P1.2.1, the CO coordinators get the physical master samples and register and make the connections for the colour master samples in screen AF in KDP, which is done quickly in a few steps. Each screen in KDP is identified by two or three letters, in this case AF refers to the master sample registration screen.

I-codes and S-codes are created in screen FBC, P1.2.2 and P1.2.3. The name of the I-code (e.g. grey) has to be entered and for the S-code area, interior or exterior, has to be chosen as well. The next available S-code cannot be searched automatically, but has to be searched manually by scrolling to the last S-code in FCE, in order to know what S-code to use. This requires an additional step and it is time consuming. The S-code must also be connected to its variant designation, colour variant, if the variant designation for the S-code has been registered by the variant coordinator. If not, this can be done at a later stage.

The connection between uncoloured and coloured master samples and I-code is made in screen FBA, P1.2.4. A coloured master sample is connected to an uncoloured master sample for each I-code.

In screen FBB, P1.2.5, the I-codes are connected to the S-code. The I-codes and variant designations are added to the S-code, which make up the colour table. The content of an existing S-code (which is similar to the new one) is often used as a reference. Each and every I-code is added to the S-code manually by typing, which requires a lot of repetitive steps and leads to a heavy manual workload and a risk for typos.

In screen FBP the S-code is authorised (connected) to at least one vehicle type and vehicle variant and to each affected function group by using a CO, P1.2.6. COs for each function group and type are connected individually. A lot of function groups are affected by a small change (like a sewing thread), which means a lot of repetitive manual work here as well. The S-codes and connections are then found in the 'colour code' section in the CO, displayed in screen CDB.

The uncoloured structure is created using a work-CO with support from the CO coordinator manual, P1.2.7. The most important thing is to use variant designation COLOURED in the variant string for assemblies (complete parts), which tells that the assembly consists of parts that are colour coordinated. And for each colour coordinated part (single part) the accurate variant designation is used.

The next step is to let the colour system create the coloured part numbers, this is done in screen FNB, P1.2.8. After vehicle type and the uncoloured part number has been entered, desired S-codes (in which the uncoloured part is used) for each vehicle variant are chosen. When this is done screen FNC shows a compilation of the chosen S-codes. If there are no errors in the uncoloured structure or connections to master samples etc. the coloured part numbers can be created. The result with coloured part numbers will be displayed in screen FCH.

The coloured structure is automatically created when the CO issue for the uncoloured part is updated. This is done in screen CAD, P1.2.9. The coloured structure is then found in the 'coloured structure' section in the CO, displayed in screen CDB. There is thus only an uncoloured structure for the part in the part list, and the coloured structures are shown in each CO. For each uncoloured part number the connected coloured part numbers are shown.

A CO coordinator manual is used throughout the process. It comprises information and instructions in order to manage Change Orders and product structure in KDP in a standardised and correct way. Information and instructions concerning colour management in the CO coordinator manual is however inadequate. The interior matrix and Surface Material List (SML), which is a document specifying surface materials, colours, grains/textures and master samples for interior and exterior parts are also used. See figure 28 for an illustration of the process model – Create part specification (P1.2). For a larger size, see appendix E.

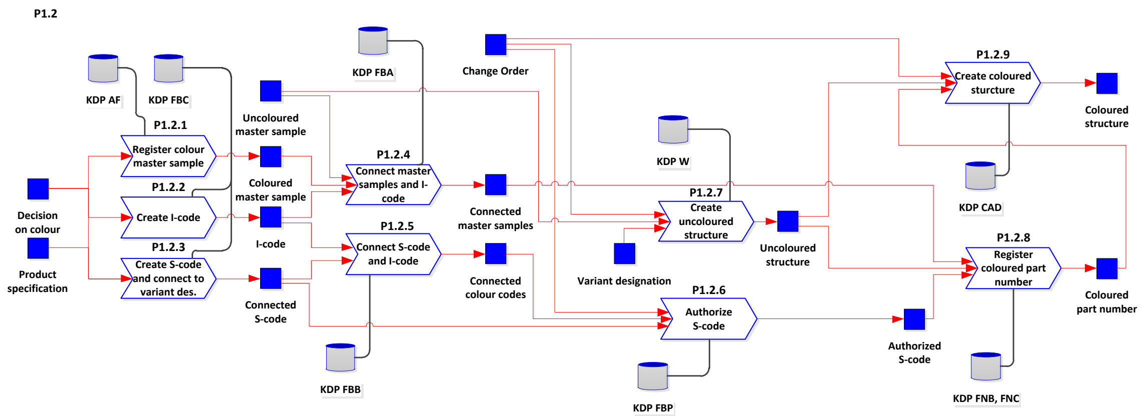



*Figure 28 – Process model – Create part specification (P1.2)*

## 4.5. Information model – Coloured part

An information model defines the content of a database and how it is constructed. An existing information model for a coloured part presented in a UML class diagram, retrieved from Volvo Cars IT, is shown in figure 29. A UML (Unified Modelling Language) class diagram describes the structure of a system through classes and their relations in a standard language (Malmqvist, 2014). Colour system related inheritance, multiplicity of relations and associations are shown in the diagram. The diamond shape represents aggregation (consists of) and the triangle shapes represent inheritance (part of).

From the class diagram one can read:

- That a part can either be coloured, uncoloured or neutral
- That an uncoloured part can have zero or many coloured parts, while a coloured part only can have one uncoloured part
- How the different master samples (coloured, uncoloured, processed, unprocessed) are connected to the coloured and uncoloured part, and is a part of the documents
- How the colour table with S-code (main colour code) and I-codes (ingoing colour code) is structured
- That a coloured part can only have one I-code and at least one S-code
- To each S-code there is one variant designation and a distinction between interior and exterior S-codes (type colour code)
- That the CO authorises (adds/deletes) the S-code, i.e. the S-code is connected to at least one type designation (or variant designation(s) within the type) and to at least one function group

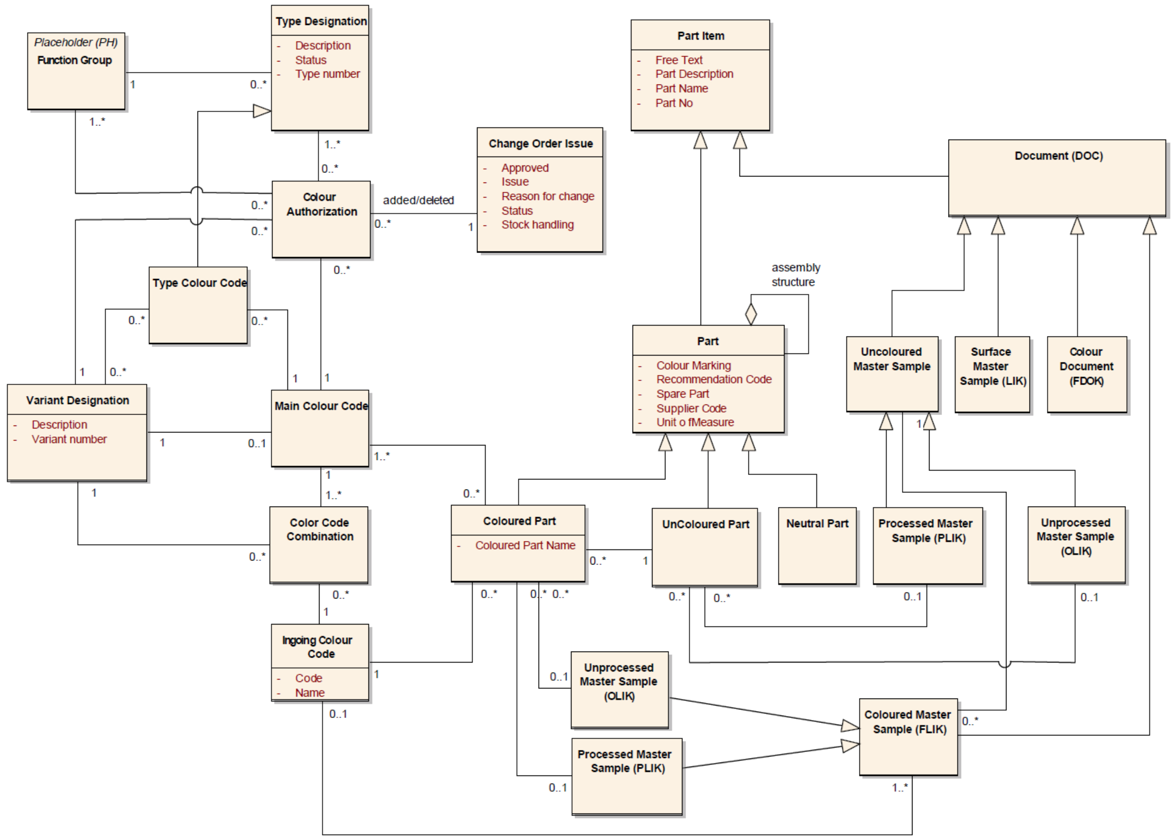



*Figure 29 –The existing information model – class diagram* (Volvo Cars IT, 2015)

This information model is detailed and focuses on the context of a coloured part. An overall conceptual information model, which puts the part in a broader context and describes other areas such as product and product structure, is found in appendix F.

## 4.6. Summary of findings

There are since recently two ways to register and manage coloured parts at Volvo Cars; using the colour system solution in KDP or using a manual procedure. They are used in different vehicle types. The manual procedure is used for interior parts in the new vehicle types for the new platforms. However, the findings are based on the colour system procedure. In order to understand and map the current situation additional specific knowledge in product structure and Volvo Cars terminology had to be documented, and in order to realise the theory behind an applied example was presented. The colour system's backbone is an uncoloured structure with colour tables containing S-codes and I-codes, which are used to control and combine the coloured parts by obtaining coloured parts and a coloured structure automatically. Changes are made to the uncoloured part, which acts like a collector, and inherits information to its coloured parts. The way that coloured parts are managed in KDP is complicated and one might have to either work with it or study it for a longer period to really understand the concept. From the process modelling section one can see that there are a lot of steps and screens in KDP with manual tasks and typing in the Create Part specification process (P1.2). The variant coordinators and CO coordinators have the greatest involvement and main responsibility when it comes to the creation of the product and part specification, which make up a coloured part and a coloured structure. It also appears that the interior matrix used throughout the process is of high importance and it is the document that controls what is about to be executed.

# 5. Analysis

In this chapter the empirical information from previous chapters is presented and analysed. An analysis of TcPMM with a comparison to KDP, a comparison between the two different working procedures at Volvo Cars and a detailed analysis of the colour system in KDP is presented. The chapter ends with a summary, which sums up and concludes the analysis. The analysis forms the basis for the proposal of improvements and recommendations for future work.

## 5.1. TcPMM in comparison to KDP

When it comes to colour management there are some clear similarities between TcPMM and KDP. The use of a collector (Less Finish part and uncoloured part), which inherits information to its coloured parts is the most significant one. Less Finish parts can be created early in the development process independent of decisions on colours and colour combinations set later in the process, as for the uncoloured part in KDP. Colour appearances or colour appearance groups together with the colour rule matrix resembles the S-code and I-codes with variant designations and master samples in KDP, in order to define and control the coloured parts. The created colour appearance is a unique and standardised combination of surface colour, texture and gloss and corresponds to the master sample in KDP, but in a computer-generated manner. One can say that the colour appearance in TcPMM acts like a virtual master sample for the part.

Regarding differences between TcPMM and KDP it is evident that colours are much more clearly described in TcPMM through the colour appearance elements surface colour, texture and gloss. The defined colour appearance in TcPMM assigns colour(s) to the CAD models, which is not the existing case in KDP. The biggest differences are thus that TcPMM defines the colour in more detail, i.e. with more attributes, and applies it to the CAD model, and that it uses a matrix-based way of controlling the parts. Different terminology is used in TcPMM, which makes the analysis and comparison a bit tricky.

However, as previously mentioned TcPMM is currently under development, which means that all areas are not yet covered with complete solutions and it is not in operation.

## 5.2. The different working procedures at Volvo Cars

As previously mentioned there is a new way of controlling colours in KDP. The manual procedure is today used for interior parts for the new platforms, vehicle type 40, 42 and 27, where the all-new XC90 is included together with other future cars within the platforms.

The reason for introducing the manual procedure is because the S-codes used for interiors have become too complex, due to that the containing I-codes and variant designations have increased rapidly. The interior is more complex, i.e. it contains a large amount of colour coordinated parts e.g. upholstery, panels, threads, and other interior details, unlike the exterior which often contain parts only in different coatings. Figure 30 shows a comparison between an S-code for interior and an S-code for exterior. The interior S-code has more rows in other pages than shown. Due to this and the way that the colour system is built up only a few number of employees in the division of Product Documentation are familiar with and advanced users of the colour system and its components, and have the ability to operate it in a proper manner, according to the manager at the division of Product Documentation.

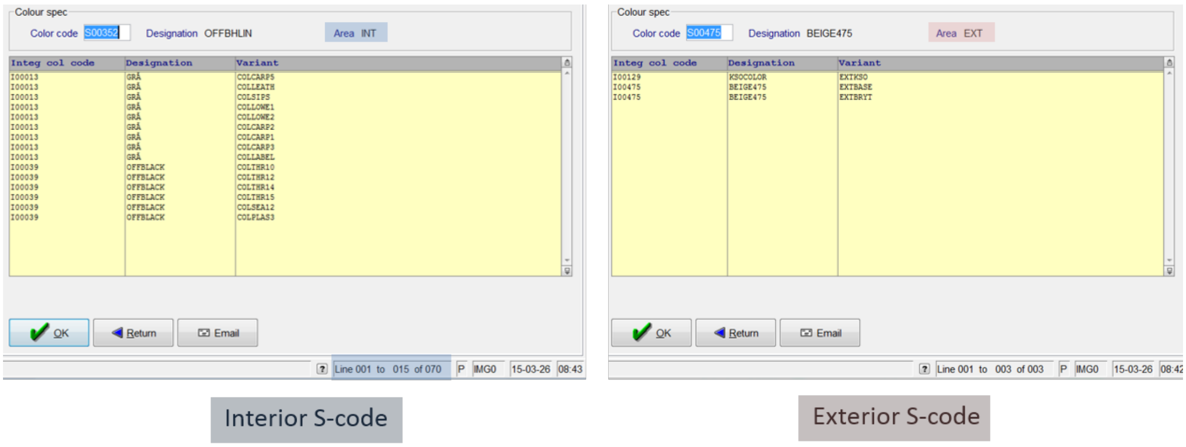



*Figure 30 – Interior S-code (left) and exterior S-code (right)* (Volvo Cars, 2015j)

Interviews with CO coordinators showed that when using the manual procedure coloured parts are not created automatically by the colour system, the registration of part numbers is done manually. The parts are managed and controlled as ordinary parts (parts that are not colour coordinated) in coloured structures in the part list, and documents are connected to each coloured part, hence uncoloured parts and colour tables with S-codes and I-codes are not used. Figure 31 shows two screens in KDP representing the coloured and uncoloured structures for door panels in the part list, one for vehicle type 42 (XC90, …) and one for 98 (S80, S80L, V70, V70XC) respectively.

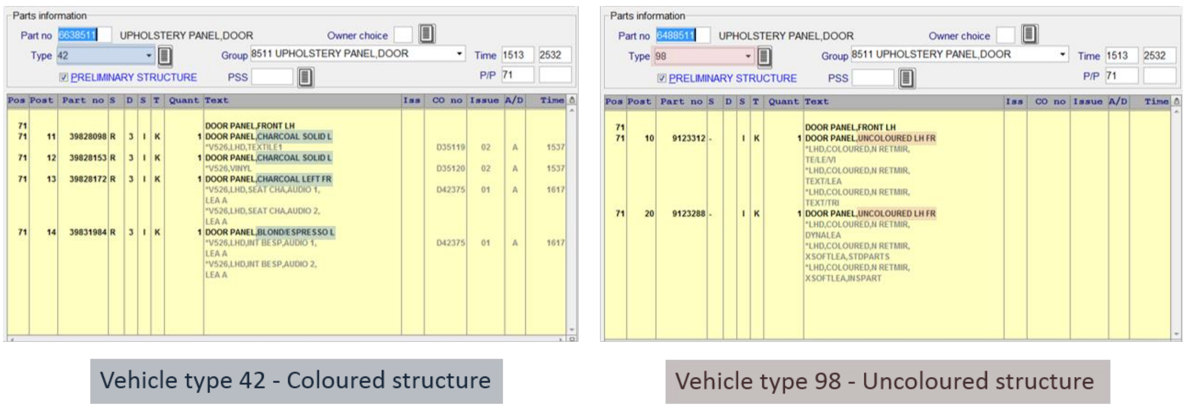



*Figure 31 – Coloured (left) vs uncoloured (right) structures for different vehicle types* (Volvo Cars, 2015d)

The drawbacks with using the manual procedure are that it entails additional work when managing coloured parts. It is time consuming to create coloured parts and manage the relations manually, and it is more monotonous which can increase typos, as is evidenced by interviews with CO coordinators. The part folder (electronic folder containing documents) has to be treated for each coloured part, according to task leader and product modeller. The benefits of not using the colour system is that the manual working procedure is well-established, hence it is well-known and familiar among a larger number of employees. It provides for improved quality assurance due to the visibility and traceability of coloured parts. It is easier to keep track of how parts are controlled when changes are made and the complexity with S-codes and I-codes disappear. Interview with purchaser showed that the purchasing department also is affected by the different structures and the uncoloured and coloured parts. In the Purchasing System SI+ that receives information for KDP, all coloured parts inherit the price from the uncoloured part as default. However if a coloured part differs in price (one or more parts are cheaper or more expensive than another) it is detached from the uncoloured part and the price is set individually for that coloured part. Another way is to use an average price for the uncoloured part, especially if many coloured parts differ in price which requires additional work. However this should to be avoided. If there is no uncoloured part for the coloured ones, the price is set for each and every coloured. When purchasing parts in an initial stage an uncoloured part is definitely to prefer since the same price often applies for all coloured parts. The interviews with the task leader and the purchaser showed that there is a request for that coloured parts should have an uncoloured part where information is inherited.

### 5.2.1. Comparison between colour system and manual procedure

Based on findings from the interviews a comparison between the colour system and the alternative manual procedure was conducted in order to facilitate when pointing out flaws and when stating advantages and disadvantages with the colour system. Figure 32 shows a comparison matrix where the two procedures are listed and divided into different areas.

| | Colour system procedure | Manual procedure |
|---|---|---|
| **Product structure** | Both coloured and uncoloured structure: Uncoloured parts in the structure (part list), coloured parts and structure in the CO. The uncoloured part inherits information to its coloured parts | Only coloured structure: Each part are treated individually |
| **Administration** | More complexity in administration, due to colour system S-codes and I-codes | Less complexity in administration, familiar working procedure, no expert knowledge is needed |
| **Manual workload** | Less manual workload, due to automated creation of coloured parts and the uncoloured collector | More parts to update, which means more manual workload |
| **System, database** | More parts to store and manage in database, the uncoloured parts | Less parts to store and manage in database |
| **Quality assurance** | Inconsistency, coloured parts inherits information from the uncoloured out of control | Good visibility and traceability due to individually treated parts (coloured), each part lives a life of its own |

*Figure 32 – Comparison matrix*

The conclusions from this section is that the major difference between these procedures is the coloured and uncoloured parts. For the manual procedure, each part has to be treated individually which generates additional work for the task leader when e.g. connecting the CAD models to the parts. The same applies for the purchasers when setting the price. However, the manual working procedure is easier to learn and understand among the CO coordinators, and it provides for better quality assurance compared to the colour system procedure. The next section presents a SWOT analysis of the colour system procedure.

## 5.3. SWOT analysis

The SWOT analysis lists the most important strengths, weaknesses, opportunities and threats with the colour system solution in KDP, see figure 33 for the SWOT matrix. The following sections emphasises and explains each of them starting with the strengths.

| Strengths | Weaknesses |
|---|---|
| Fast adaptation and integration | A lot of manual typing and several steps in KDP |
| Highly customisable and adaptable to change | Complexity within the S-codes |
| Knowledge, competence and experience | Experience and deep knowledge only amongst a few |
| Thorough and optimised colour system solution | Lack of communication of information |
| Well-established working procedure | Mix of structures/working procedures |
| Automated creation of part numbers and structure | No follow up on manual procedure |
| One generic (uncoloured) structure | Limited functionality in KDP |
| Simple and fast way of adding new colours | Interior matrix not consistent or standardised |
| Documents connected to only one part | New coloured parts get incorrect part information |
| Changes made only to the uncoloured part | Hard to maintain good quality assurance |
| | Additional parts to store and manage in database |

| Opportunities | Threats |
|---|---|
| Improve communication and become clearer | Less resources in complex products in PLM/PDM area |
| Increase understanding and knowledge | Devastating effects of minor changes |
| Decrease manual workload by streaming steps and typing in KDP | Holding company interference and global production |
| Merge screens in KDP | Lack of clarity and consistency in communication |
| Implement experience to future PDM systems | Phase out of existing solution |
| Benchmarking of companies facing the same challenge | |

*Figure 33 – SWOT analysis matrix*

### 5.3.1. Strengths

The self-developed PDM application KDP provides for a fast adaptation and integration in an altered working environment and working conditions. Volvo Cars are thus not dependent on any specific supplier, unlike COTS (Commercial Off The Shelf) applications. Within KDP the colour system solution has been developed for a long time and yet it is still highly customisable and adaptable to change, since Volvo Cars is the source code owner. Due to this there is a lot of deep knowledge, competence and experience with the existing solution within the company. The colour system has been up and running for a long time, for that reason it is a thorough and optimised solution with an established working procedure, as evidenced by interviews with application engineers in the division of PLM.

One of the key strengths is the automated creation of part numbers and coloured structure for coloured parts, which minimises the manual workload and facilitates when setting the structure and managing colour and interior combinations, according to the CO coordinators. When there is a change in a part, it is done in the uncoloured part, and the information for the coloured parts are updated automatically. Interviews showed that it provides for a fast and simple way of adding new colours or colour combinations. The generic uncoloured structure, with the coloured structures in the COs, gives an organised and consistent product structure, where the part structure only has to be created once. The managing of the part folder is done for the uncoloured part, which acts like a collector, and information is then inherited to the coloured parts. Documents (e.g. CAD models) in the part folder are connected to only one part, the uncoloured part, instead of each and every coloured, which facilities according to task leader and product modeller. Part validity is changed and weight is updated only for the uncoloured part. This is time-saving and facilitates their daily work. When the same price applies for all coloured parts, the purchasers can use only the uncoloured part and all coloured parts inherit the price information from this, which is timesaving. For exterior parts the colour system works very well and is vital as long as the exterior complexity remains the same.

### 5.3.2. Weaknesses

The part specification process model (P1.2) shows that there is still a lot of manual typing, which requires a lot of steps and where there is a risk of typos and errors when using the screens in KDP. This applies in particular to the creation of I-codes and S-codes (P1.2.2 and P1.2.3), connections of I-codes to the S-code (P1.2.5) and connection of S-code to type and function group using a CO (P1.2.6).

One of the main weaknesses is that the colour system has become complex, due to the increase of I-codes and variant designations within the S-code, especially for interior. Due to this complexity only a few are familiar with and have deep knowledge and experience in the colour system and its components, according to the manager at the division of Product Documentation. The uncoloured parts used as collectors are also additional parts to store and manage in the database, which requires and occupies storage space. The interviews showed that there was also lack of communication of information when introducing the manual procedure for interior parts in vehicle type 40, 42 and 27. The two different structures and working procedures, colour system and manual, creates confusion and inconsistency, and there was no follow-up after the manual procedure was introduced. KDP as application has limited functionality and there is a challenge in embedding additional functionality, e.g. copy/paste and drag-and-drop functions, to the interface. According to interviews the layout and content of the interior matrix used at the division of Product Documentation plays an important role when creating the product and part specification. However, a weakness is that there is no standardised layout or content requirements for all interior matrices. This has led to that the interior matrix for special vehicles has a different layout and is less detailed.

When coloured parts and the coloured structure are created automatically, the resulting information (coloured parts) is derived out of control, as is evident from interviews with CO coordinators and task leader. For example if a new colour is developed for an old part, e.g. a clip, this new coloured part inherits part information (task number, part version, validity, weight) from the uncoloured part, which information might be old and incorrect. This information has to be changed manually, according to the CO coordinators. The quality assurance is not as good as compared to the manual procedure, where visibility and traceability of coloured parts and structures are more apparent.

### 5.3.3. Opportunities

There is a great opportunity to better communicate the importance and significance of the complexity of the colour system and working procedure related to variants and details in the product's interior. This could be done in the CO coordinator manual or in other printed documentation. Since there is a lack of communication of information, especially when it comes to the different working procedures and the colour system itself, there is a chance to stress these related issues. This could also be done by increasing the understanding and knowledge, through training and instructions, in each of the working procedures, the colour system and the manual procedure. When it comes to the application there is a possibility to decrease the manual workload and make it more efficient, especially for the processes mentioned in the weaknesses section above. This could be done through automation or improved or merged screens in KDP related to the colour system. Further the gained experience and knowledge could be utilised and implemented into TcPMM or other technologies for future replacement, or the other way around. A comprehensive benchmark of other companies facing the same challenge might also be a great opportunity to see if there are any other companies within the vehicle industry that uses a solution for controlling colours and colour combinations (cf. the colour system in KDP). If so, lessons can be taken from their solutions and way of managing colours.

### 5.3.4. Threats

One of the main threats is that less resources are devoted to how mass customisation and product complexity affect the PLM and PDM area. As compared with e.g. product design where platform development, modularisation and commonality thinking are at the forefront with cutting edge technology. Another major threat is that even minor changes and intended improvements in KDP may be devastating due to downstream systems, which are dependent on information derived from KDP. The lack of clarity and consistency in the communication of changes may also be a threat for future changes and development. A major step is a possible future phase out of KPD which can lead to a long transitional period with disturbances and teething problems. A long with this the involvement of the holding company Geely, and the global production that in entails, create more challenges.

## 5.4. Summary of analysis

There are some clear similarities between TcPMM and KDP. Especially the use of a part that acts like a collector. A distinctive difference is the way of controlling the parts. In KDP variant designations are used in the uncoloured structure, which are also found in the colour tables. In TcPMM the parts are controlled using a matrix-based approach with checkboxes. The method of defining colour appearances is also much more evident in TcPMM compared to KDP, where only physical master samples give information about the colour attributes. When it comes to the user-interface it seems like the more user-friendly intuitive user interface in TcPMM provides for a more apparent and less complex way of controlling parts. The user-interface in TcPMM also provides for better functionality compared KDP.

A manual working procedure has been introduced in order to manage the complexity of the colour system procedure. The manual procedure requires more manual tasks, but the biggest difference is that no uncoloured parts (collectors) are used, which according to interviews entails additional work for the task leaders when connecting the documents and when adding attributes for the coloured parts. The same goes for purchasers when setting the price. When it comes to the colour system procedure the main strengths are the automated creation of coloured part numbers and as previously mentioned the uncoloured part. The main weakness is the complexity, mostly due to the amount of I-codes and variant designations within each S-code. There are also still a lot of manual steps and typing in the KDP screens related to colour management, especially in the process where the part specification is created. There are great opportunities for continuous improvements in KDP screens and in the communication of information for a more efficient colour management. This could lead to reduced manual steps and time for typing and broader knowledge and awareness among the stakeholders. Although KDP is a self-developed application that is customisable and provides for fast adaptation it has limited functionality. However, in order to overcome the problems with the complexity, major changes or an all-new approach might be needed.

# 6. Proposal of improvements

This chapter presents a bulleted list of screened and refined suggested improvements divided into two areas; continuous improvements and more extensive suggestions. Potential effects of the suggestions are also presented.

## 6.1. Continuous improvements

- When creating new S-codes and I-codes in screen FBC, see figure 34, the CO coordinators have to manually search the first available code number in another screen, FCE. A solution is to insert a checkbox next to the colour code field in screen FBC which, when it is check marked, automatically picks the first available S-code or I-code. For the CO coordinators this will reduce a step in the process and the time to search for the next code number to use.

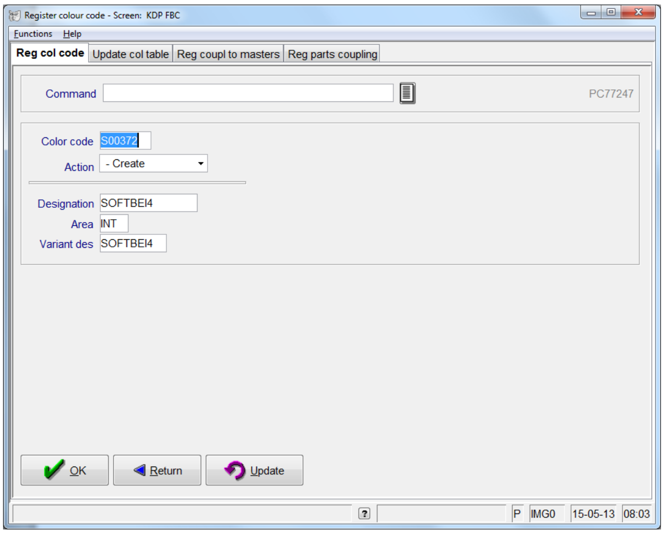



*Figure 34 – Screen FBC, where new S-codes and I-codes are created* (Volvo Cars, 2015n)

- There is a lot of manual typing when adding I-codes and variant designations to an S-code in screen FBB, see figure 35. In most cases an old S-code, similar to the new one, is used as a reference, and only a few I-codes are changed. An improvement is to implement a solution that makes it possible to copy or duplicate an S-code containing I-codes, which then can be edited and adjusted according to the new needs. A possible solution will decrease the manual typing for the CO coordinators in this screen a lot.

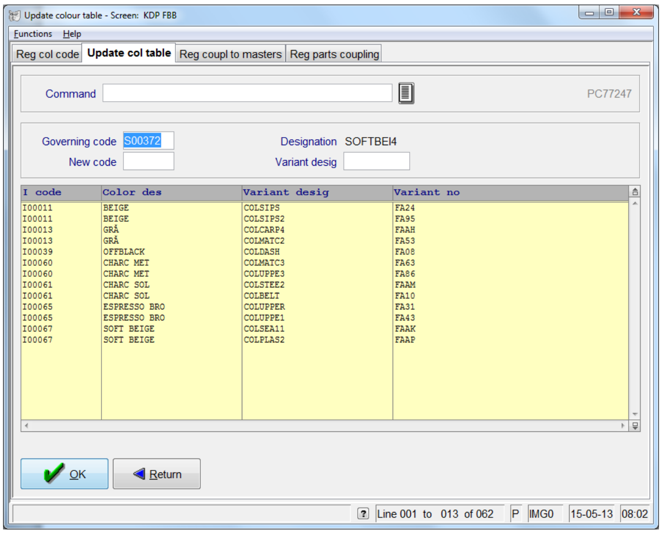



*Figure 35 – Screen FBB, where new I-codes are added to the S-code* (Volvo Cars, 2015o)

- In screen FBP the S-codes are authorised, meaning that they are connected to vehicle type and vehicle variant and affected function group using a CO, see figure 36. This is done for each and every function group that is affected by the change. A solution is to insert a feature that makes it possible to enter and pick several data in one field, e.g. when choosing vehicle variant one may choose two or more at the same time. As a suggestion when choosing vehicle variants Y352; Y413; L421 can be entered, and all variants are connected to the S-code and function group at the same time. This functionality may also improve other screens where there is a request for choosing several alternatives at once. Another solution is to let the entered data in the fields remain after a certain action has been taken. When the next action is about the get performed only one field has to be changed. Potential benefits from these solutions are the reduction of steps used in this screen and the time for typing. The functionality from both of the suggested improvements in this screen might also apply to other screens in KDP, which is beneficial.

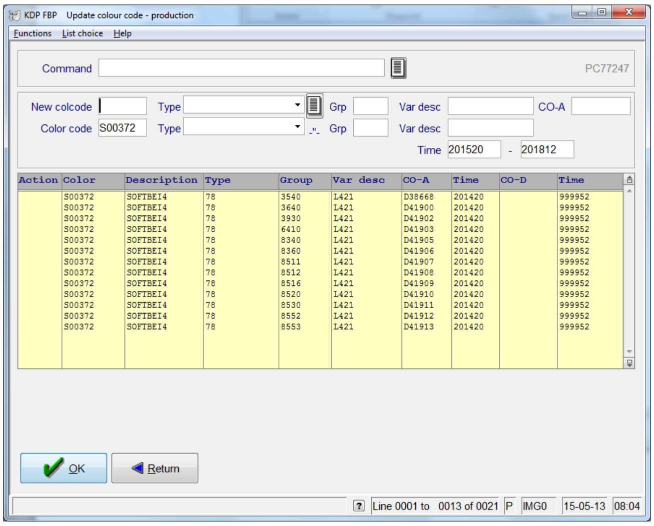


*Figure 36 – Screen FBP, where the S-code is authorised* (Volvo Cars, 2015p)

- Coloured parts that are created automatically from an old uncoloured part inherit old and incorrect part information. Today this information has to be change manually, especially task number for a new coloured part. A solution to this is to let the coloured parts inherit some of its part information from the S-code's CO when new coloured parts are created. Documents like CAD models and weight must however be inherited form the old uncoloured part. A possible solution will enhance the quality by preventing incorrect part information and thereby avoiding additional work.
- In KDP there are a number of screens (screens starting with F) that have to do with colour management. In order to inform to clarify, help and guide the different users in their daily work short process descriptions, instructions, help guides and other important information can be linked from these screens in KDP. The process descriptions, instructions and help guides in the form of PowerPoints, process models and textual descriptions can be available on the Engineering Portal - PLM Methods on Volvo Cars intranet, see figure 37. It can complement the other information used to support the daily work in other applications such as Teamcenter and CATIA, which is available at the Engineering Portal - PLM Methods. Variant coordinators, CO coordinators, task leaders, design engineers and other users of the F-screens in KDP might benefit from an implementation of this solution. A lot of different error sources incurred as a result of user uncertainty or lack of knowledge can be eliminated. In addition to this more information about how coloured parts are managed, including how the colour system in KDP is built up and the different working procedures, should be specified in the CO coordinator manual.

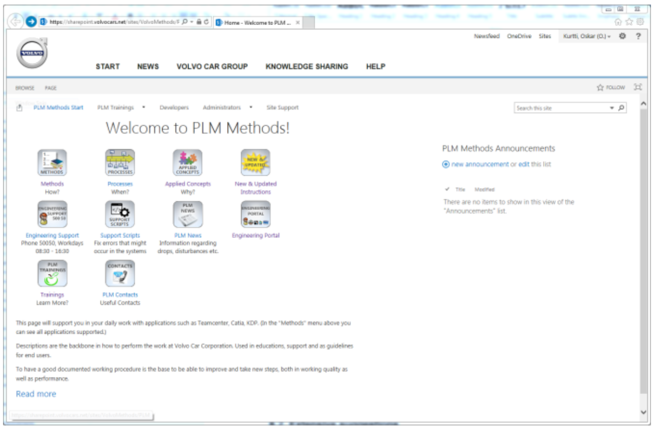


*Figure 37 –PLM Methods website on Volvo Cars intranet* (Volvo Cars, 2015q)

- Some interior matrices used at the division of Product Documentation are since recently available in Teamcenter. They contain information according to requests from variant coordinators and CO coordinators and are detailed. However, the interior matrix for special vehicles differs from the other interior matrices in terms of content and it is not as detailed. A suggestion of improvement is to change, adapt and standardise all of these matrices so that one common appearance and approach is used. This might improve the quality in the daily work for variant coordinators and CO coordinators in terms of a standardised and common approach and eliminated inconsistencies.
- In order to increase Product Documentation's involvement when a new interior or exterior is decided and the interior matrix is built up the variant coordinators and CO coordinators could attend to a start-up meeting early in the process when decision on interior or exterior is taken. This is currently underway but it needs to be highlighted. A way of emphasising this is to add an instruction of it in Volvo Cars' Business Management System (BMS). This could reduce iterative steps when establishing the interior matrix, thus it could save time and reduce uncertainties.

## 6.2. Extensive suggestions

- The interior matrix used today could be extended to more of an animated interior matrix where rows, columns and areas in the matrix links to useful information either in KDP, Volvo Cars intranet or in Excel reports, describing e.g. the coloured product structure and coloured parts for a certain S-code, upholstery, or other coloured interior parts. Links can also lead to the VEDS (Volvo Engineering Data Search) intranet site, where part information in KDP is presented in a more distinctive and intuitive way. The knowledge of what information that is vital and interesting and the layout and appearance of this "dynamic" interior matrix exists within the division of Product Documentation. This solution might develop an understanding and broaden the knowledge among the CO coordinators and variant coordinators for improved quality assurance.

- Another extensive solution is to replace the colour system in KDP completely with a module outside KDP tailored to manage colours and colour combinations. A totally new way of managing colours might be needed in order to reduce the existing complexity. The module may include a surface material library containing descriptions of all colours and materials used for defining the appearance of a part. As a suggestion catalogues within the surface material library can list e.g. different type of leathers, textiles and sewing threads for upholstery. Using a module outside KDP provides for increased flexibility in user interface and functionality. There are no restrictions to the functionality within KDP, yet the new module must deliver information to KDP. For this module inspiration and knowledge can be taken from the colour management in TcPMM, especially the user interface, the colour definition and appearance and the matrix-based way of controlling the coloured parts. Also here the knowledge of which main components that is needed exists within the division of Product Documentation. Such extensive solution can improve the complete approach when it comes to colour management in terms of e.g. new processes, tasks, roles and documents. However, it might also cause challenges in e.g. further development and future running-in problems.

# 7. Discussion

This chapter discusses the project and comprises responses to the research questions, a discussion of the project's validity and credibility, and the transferability of the results.

The first research question *(RQ1)* was: *How are coloured parts and colour combinations managed in PDM systems?* During the thesis project very few publications about colour management in PDM systems could be found. Therefore this report gives no clear answers to how coloured parts and colour combinations are managed in PDM systems in automotive companies. The reason for not finding any publications in the topic may depend on several things, but most likely due to the highly customised in-house develop PDM systems that companies use, and due to the confidentiality within the automotive companies. On the other hand one cannot exclude the fact that some useful research information might have been missed or overlooked unintentionally in this thesis project. A comprehensive benchmark of other companies was not within the scope of this thesis. This might be a way of mapping how coloured parts and colour combinations are managed in PDM systems today. However, such benchmarking including case studies requires a lot of patience and is probably very time-consuming to conduct.

The second question *(RQ2)* concerned how coloured parts and colour combinations are managed in Volvo Cars PDM system regarding; *a) What processes, tasks, roles and information are used?* and *b) What are the strengths and weaknesses with Volvo Cars' existing colour management?* When it comes to the way that Volvo Cars manages colours and colour combinations in their PDM system it was clear that it is as complex as it was stated. A colour system solution within the PDM system KDP, with the main elements the uncoloured structure and colour tables, is used to obtain coloured parts and a coloured structure automatically. An uncoloured part is used as a collector, which inherits part information to its coloured parts. The CO coordinator proved to have a vital role in the process of creating these coloured parts, using different screens in KDP related to colour management. However, the knowledge in the colour system working procedure is only concentrated to a few. The interior matrix together with the CO coordinator manual were the most important documents used throughout the process. The main strengths with Volvo Cars' existing colour management are the automated creation of coloured part numbers and the uncoloured part that acts like a collector. The main weakness is as mentioned the lack of knowledge among the users due to the complexity of the existing solution. It was also found that some everyday tasks are time-consuming, especially steps and typing in colour management screens in KDP.

*How can the way coloured parts and colour combinations are managed at Volvo Cars be improved (RQ3)?* A number of proposed improvements derived from the findings and analysis have been presented. The stated proposals are more of kaizen type, meaning continuous improvements of the existing solution, comprising mainly improvements for more efficient colour management tasks and screens in KDP. Some of the stated improvements need further refinement and additional details in order to become available for a plan of implementation. The thesis project was conducted under a too short time period to be able to propose entirely new and more concrete and drastic proposals of improvements in detail. Some less detailed extensive suggestions were however presented, for example a module outside KDP aimed at managing colours and colour combinations in order to improve and solve the colour management complexity at Volvo Cars.

The chosen interview subjects during the project might not represent all internal interests when it comes to colour management. The interview subjects might also be biased meaning that there is no assurance that the collected data is objective and valid. However, the interview subjects were chosen based on their knowledge and competence in Volvo Cars' colour management and on internal contacts provided by the supervisor at Volvo Cars, which strengthens the credibility of the findings. The interview subjects have been dedicated and interested in the project. A recurring problem was though that several interview subjects expressed themselves in technical terms, which led to that it was hard to understand and to keep up while interviewing. The analysis and result on the other hand might have been different if the project had been carried out by someone else, or by a group of two with other personal backgrounds and prerequisites, which may lead to different discussions within the project group or generation of other ideas. However, in this project the process models were validated by variant coordinators and CO coordinators, and the ideas were evaluated, refine and acknowledged together with people at Volvo Cars. The thesis project was carried out individually. Due to this the possibility to discuss upcoming problems and solutions has been limited. Working alone in a project like this gives a great responsibility, but also the ability to influence and the possibility for personal development, which was appreciated. A lot of time was spent on mapping and describing the current situation at Volvo Cars. In order to understand the colour management process clearer and to get even deeper insight in the colour system in KDP and the difficulties that it entails one might have to work as a CO coordinator for at least a couple months. Regarding the choice of methods other PLM specific analysing methods could have been used, but in that case customisation and adaption to the project would have been needed. However, the chosen methods was found to be well-suited for the achievement of the project goals.

The results from the project report can be applied to other automotive companies that use PDM systems for managing coloured parts. Some of the results might also be transferred to other industries where a wide range of products are offered or where PDM systems for product structuring are used, e.g. the clothing or footwear industry. The suggested continuous improvements are however highly individual and adapted to the colour system solution in Volvo Cars' PDM system KDP.

# 8. Conclusions and recommendations for future work

With support from the content in previous chapters in the report this section concludes the project and presents recommendations based on findings throughout the project.

## 8.1. Conclusions

The state of the art analysis showed that there are a lot of research about the trend and importance of product complexity and variety going on, and that there is a need and request for managing customised and personalised products in PDM systems. However, within the area of colour management in PDM systems information was too insufficient in order to be able to draw conclusions in how coloured parts and colour combinations are managed in PDM systems. In literatures and research articles colours might have been neglected and just treated as any attribute, but coloured parts have to be treated differently (individually), due to all of its own attributes and the fact that it is a part that may belong to several different assemblies and subassemblies that in the end make up different interiors or exteriors. A conclusion from the literature study is also that this creates a great opportunity to benchmark other automotive companies' PDM systems. The research also showed that there is an emphasis on the consistency of product structuring. When the working procedure and way of managing coloured parts were changed at Volvo Cars confusion and inconsistency arose. Here, communicating information about the changes and the consequences is vital. There are some clear similarities between the colour management in TcPMM and KDP, but there are also a lot of differences. The use of a collector and a distinct definition of the colours and materials might be a proper way of managing coloured parts and colour combinations. However, in order to draw further conclusions one might have to investigate several other PDM systems to see if there is a common approach or trend.

The colour management at Volvo Cars including the colour system solution in KDP is complex. The way that the colour system creates and controls colours and colour combinations is complicated. The fundamental principle of the colour system solution in KDP is developed to operate under the conditions given back when it was introduced, in the late 1980s. Time has changed and the products look different now, and in the future the cars may become even more complex. It is clear that the colour system solution in KDP cannot handle today's platform's entire lifespan. Minor improvements through the years has led to how it is today. Due to this the true knowledge is concentrated to only a few.

The main strengths with the colour management and the colour system in KDP are the automated creation of coloured part numbers and the uncoloured part, the collector. This minimises the manual workload when new colours and colour combinations are introduced or when making changes to documents or attributes for a coloured part. The main weakness is that the colour system in KDP is too complicated to understand and to be used smoothly for today's products, therefore only a few are familiar with it and able to operate it properly. Another weakness is that there are still a lot of manual work, which requires a lot of steps and where there is a risk of typos and errors when using some of the screens in KDP related to colour management. Especially the screens in tasks performed in the create part specification process. It seems like the colour management in Volvo Cars' PDM system, with both the colour system solution in KDP and the introduced manual procedure, is a compromise in order to keep the majority of the stakeholders satisfied and at the same time be able to handle the product complexity and the complications that the colour system solution entails. There is no clear way of optimising the colour management at Volvo Cars, but there is potential for continuous improvements of the current situation.

## 8.2. Recommendations for future work

A recommendation is to investigate the colour management in other automotive companies' PDM systems. For example KOLA at AB Volvo, Spectra at Scania or Smaragd at Daimler AG, in order to see if there are solutions similar to the colour system solution in KDP, or if there are similarities or differences to how TcPMM intends to solve the addressed issues.

The lack of knowledge and awareness in the colour management area, as evidenced by interviews, calls for better dissemination of information, especially about the colour system solution in KDP and the different working procedures. It is recommended to, through written documentation or other media highlight these parts. It is recommended to conduct a thorough follow-up on the different working procedures, with input from all internal interests, in order to evaluate the impact of the introduction and the effects from potential changes. It is also recommended to investigate the possibility to establish the colour management processes firmly, e.g. by creating instructions and standardise tasks and documents used throughout the process and introducing plans of actions for upcoming problems.

As short-term measures to improve the way coloured parts and colour combinations are managed at Volvo Cars a set of continuous improvements have been presented, which might eliminate some of the manual steps and the time spent on typing, as well as it could lead to increased understanding among the users. A recommendation is to further investigate the feasibility of these suggested improvements, and the effort versus the reward of a potential implementation. However, in order to overcome the complexity long-term measures in terms of more extensive actions like a completely new colour system solution are recommended. This might also lead to a positive side-effect in increased quality assurance. With only minor continuous improvements it might be hard to solve the most serious complexity issues. A change of this magnitude however requires a lot of time for further development and it will probably lead to a long running-in period. To meet upcoming needs and future trends in the long-term, one might also have to rely on customised COTS products, such as TcPMM, with guidance from experts in the PDM field.

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# Appendix

## A: Role descriptions

Manager Product Documentation (PLM manager) – Manager at the division of Product Documentation

CO coordinator – Coordinates and establishes Change Orders in KDP and manages the part specification in the division of Product Documentation.

Variant coordinator – Responsible for variant and product structure and manages the product specification in the division of Product Documentation.

Task leader (former KU) – Owner of a task and leader of a design engineer team. Manages and is responsible for documentation and development of delivery units within the task.

Design engineer – Develop technical solutions and documents describing systems and components according to the task leader's deliveries.

Product modeller – Assists the task leader with the structure in Teamcenter (CAD structure) according to information in KDP.

Application engineer – Develops technical solutions and documents for engineering applications such as KDP.

Purchaser – Responsible for purchasing related tasks

## B: Interview guide

### Interview objectives

Find users’ perceptions, find and focus on what is unknown, find weak spots to secure newsworthiness and focus the attention. Find strengths, weaknesses, opportunities and problems. Quantify the manual workload, and generate ideas and possible solutions.

### Introduction

Initially present a short background to the master´s thesis project. Highlight that the questions are about the colour system with colour control in focus. In some cases use the process model as support when stating the questions, in order to elicit and facilitate for interviewee to explain and express. Also use the applied example as well, in order to facilitate when pointing out important information and relate to reality.

### Role and tasks

What role do you have in the process?

Show and explain how you work (input/output, when from who/where). Occurring errors during work? Tasks’ frequency?

Where is the manual workload overrepresented?

Can any manual workload be atomised?

### Location of weak spots and unknown areas

Where does problem arise? Why?

Is there lack of knowledge somewhere in the process? Where? Why?

Are there bottlenecks somewhere? Where? Why?

### Information and instructions

Where is most documented information or instructions needed? Why?

Is there a lack of instructions somewhere? Where? Why?

### Needs and requirements

What necessities does the system and working procedure need to fulfil?

What are the most important needs and requirements of the process and system from your point of view?

**Strengths and weaknesses**

What do you like with the existing working procedure?

What don’t you like about it?

Can you mention any advantages with today’s working procedures?

Can you mention any drawbacks with today’s working procedures?

**Proposal of improvements**

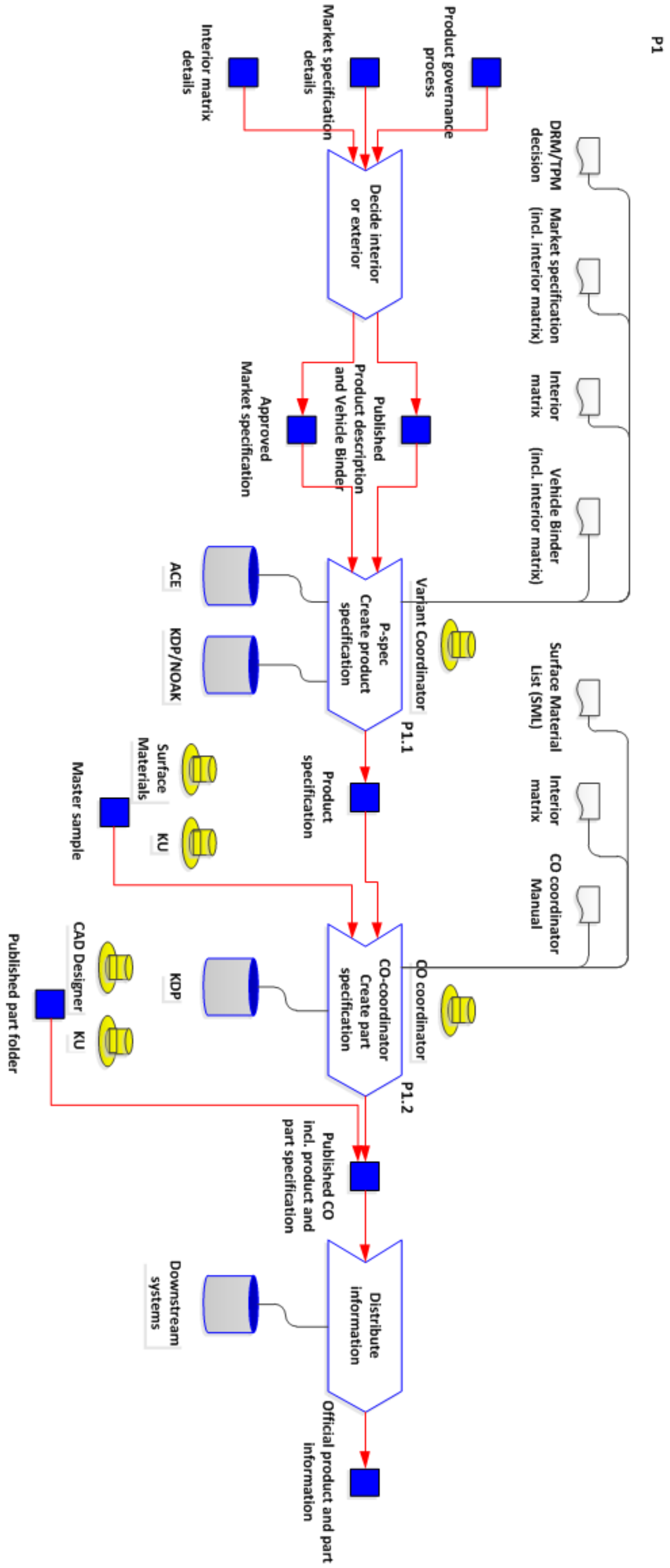
Do you have any ideas or suggestions of improvements that could improve the process?

**Miscellaneous**

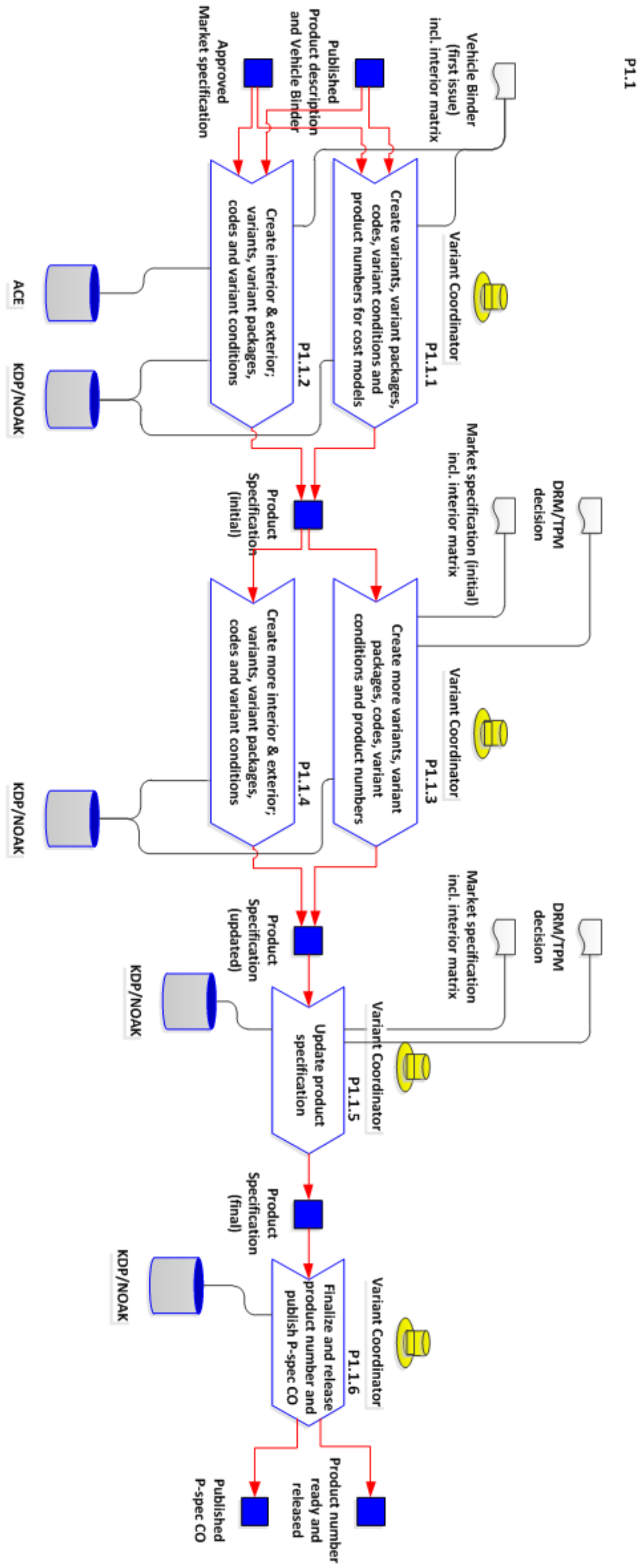
Who else knows about the process and your tasks?

Do you have any contacts that have valuable information that could be useful?

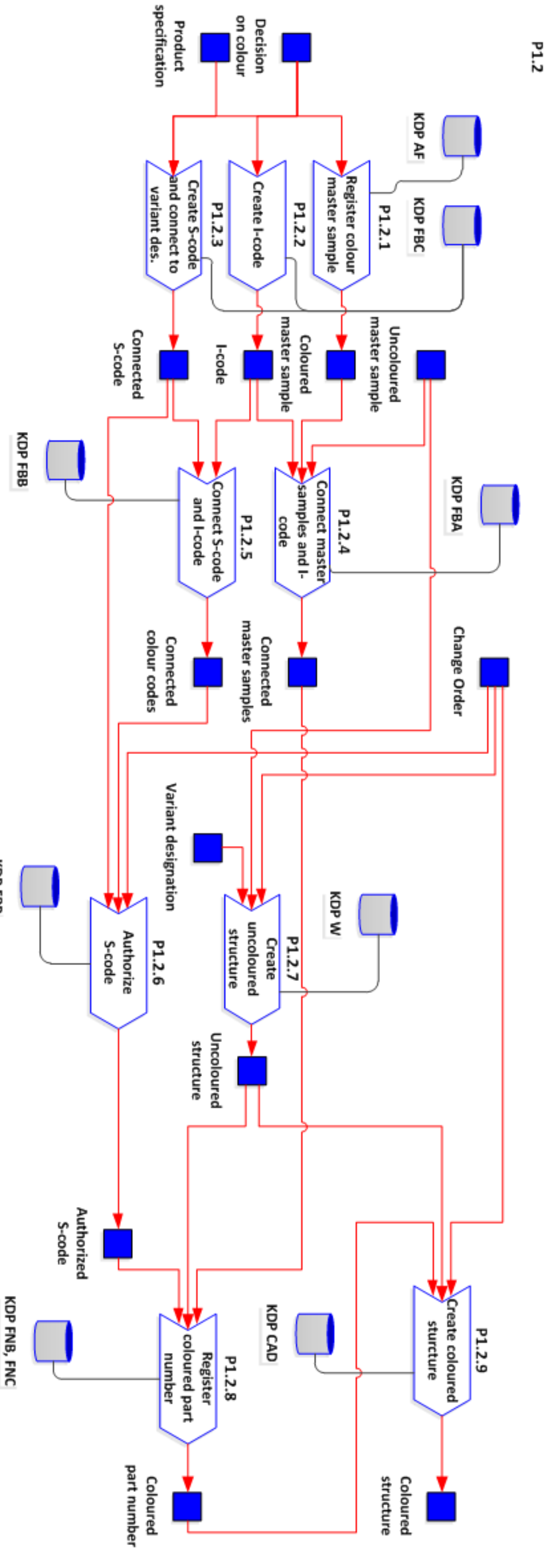
## C: Process model – Colour management overview (P1)



## D: Process model – Create product specification (P1.1)



## E: Process model – Create part specification (P1.2)



# F: Information model – Conceptual model class diagram