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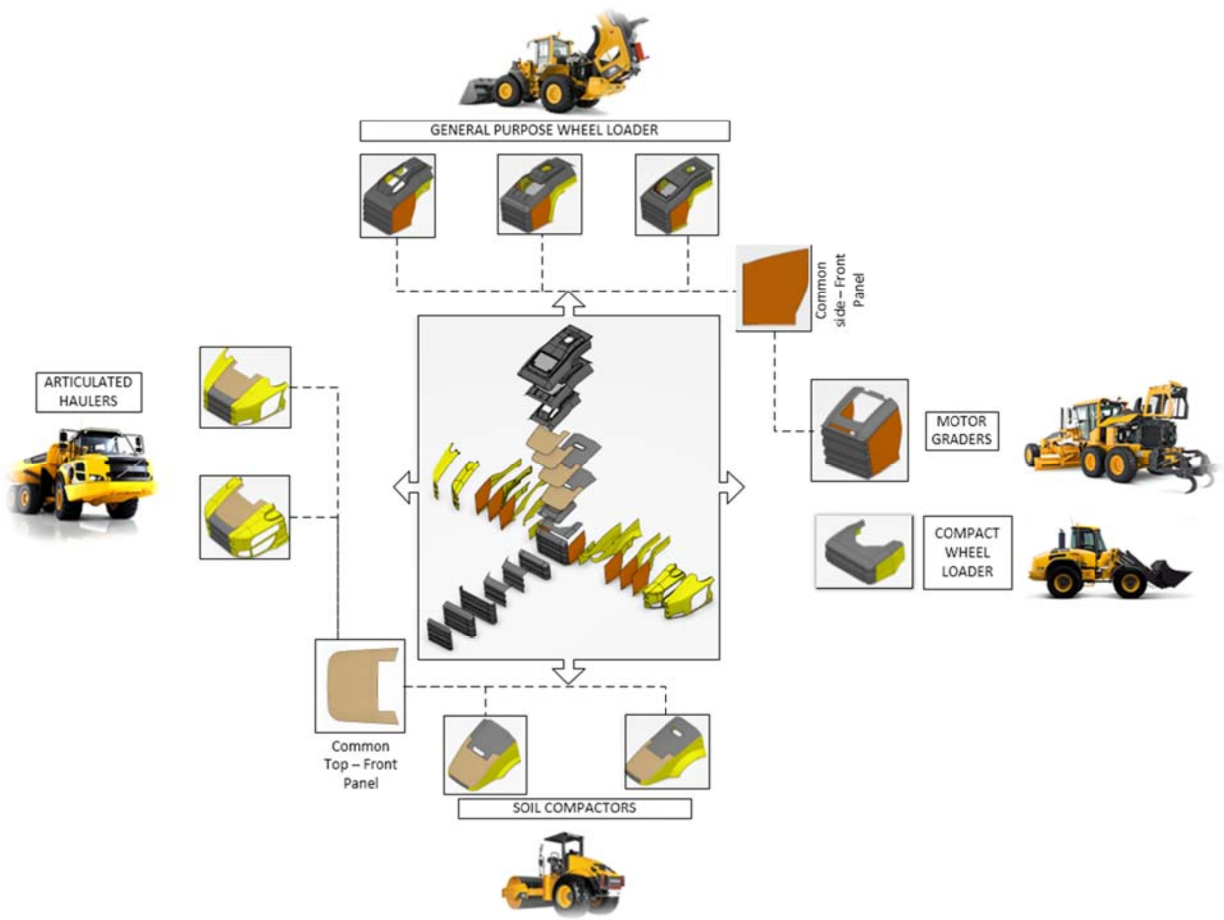

Modular Design and Documentation of Construction Equipment Hoods using Dassault Systemes 3DExperience Platform

Master's thesis in Product Development

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2015

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Cover:
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ABSTRACT

Modular Design and Documentation of Construction Equipment Hoods using Dassault Systemes 3DExperience Platform

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In order to reduce the product complexity and find synergies between different product categories, Volvo Construction Equipment has started an initiative called Common Architecture Shared Technology (CAST), which concentrates on establishing the modular product architecture for different components in a vehicle. CAST helps in reducing the complexity of the products by understanding the functional relationship to the design and thereby identifying synergies which will help in commonizing parts, thus reducing the part numbers. The Master thesis mainly concentrates on the hoods of five product categories. The generic product development methodology defined in the book "Product Design and Development (Ulrich and Eppinger, 2012) and VCE's internal CAST methodology are used as guidance throughout the project.

The 3DX platform from Dassault Systemes is used to document the modular solutions. The 3DX platform helps in capturing requirements, allocating them to different entities, defining different configuration features and options based on technical rules and creating different product configurations.

The study helped in identifying the synergies in design between the five product categories by functionally decomposing the different hoods and finding the relationship both within and between product categories. This resulted in a modular product architecture which helped to reduce the number of parts from 32 to 26 and further down to 20 by the proposed changes. The different modules were defined using 3DX platform and various technical rules were established to show different possible configurations of hoods.

Keywords: Synergy, functional breakdown, CAST, technical rules, capturing requirements configurations

ACKNOWLEDGEMENTS

This report, "*Modular Design and Documentation of Construction Equipment Hoods using Dassault Systemes 3DExperience Platform*" is written as a Master's thesis during the fall of 2014. It is the final project for the MSc. Program of Product Development. This thesis is a collaboration between Volvo Construction Equipment and Dassault Systemes.

Firstly, I would like to thank my supervisor and mentor at Dassault Systemes, Lars Tengelin for all the support and encouragement provided at each and every stage of the project work and the guidance provided during the reviews.

With profound respect, I express my deep sense of gratitude and sincere thanks to the team at Volvo Construction Equipment. Especially Lars Jung, Sofia Hällgren, David Carlson and all the people who have contributed to the project.

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I would like to add a special thanks to Frederic Penso and Francois Sychowicz for all the extended support provided throughout the project.

Lastly I would like to offer my best regards to all those who supported me in any respect during the course of the project.

NOMENCLATURE

DS	-	Dassault Systemes
VCE	-	Volvo Construction Equipment
3DX	-	3DExperience Platform
CATIA	-	Computer aided three dimensional interactive application
ENOVIA	-	Enterprise innovation interactive application
CAD	-	Computer Aided Design
PLM	-	Product Life Cycle Management
USP	-	Unique Selling Point

TABLE OF CONTENTS

1. INTRODUCTION

The following report describes the background, methods, concept design and development, technical documentation, assembly methods of the Master Thesis Project “**Modular Design and Documentation of Construction Equipment Hoods using 3DExperience platform**”.

1.1 BACKGROUND

Volvo Construction Equipment’s (VCE) offers products and services like wheeled and crawler excavators (diggers), articulated haulers (dumpers, dump trucks), wheel loaders, pavers, compactors, backhoe, etc. for industries like quarries, energy related industries (oil & gas), heavy infrastructure, forestry industry etc. VCE as a company grew by acquiring several other companies around the world (Figure 1). Consequently it had to manage several new CAD and PLM systems simultaneously.

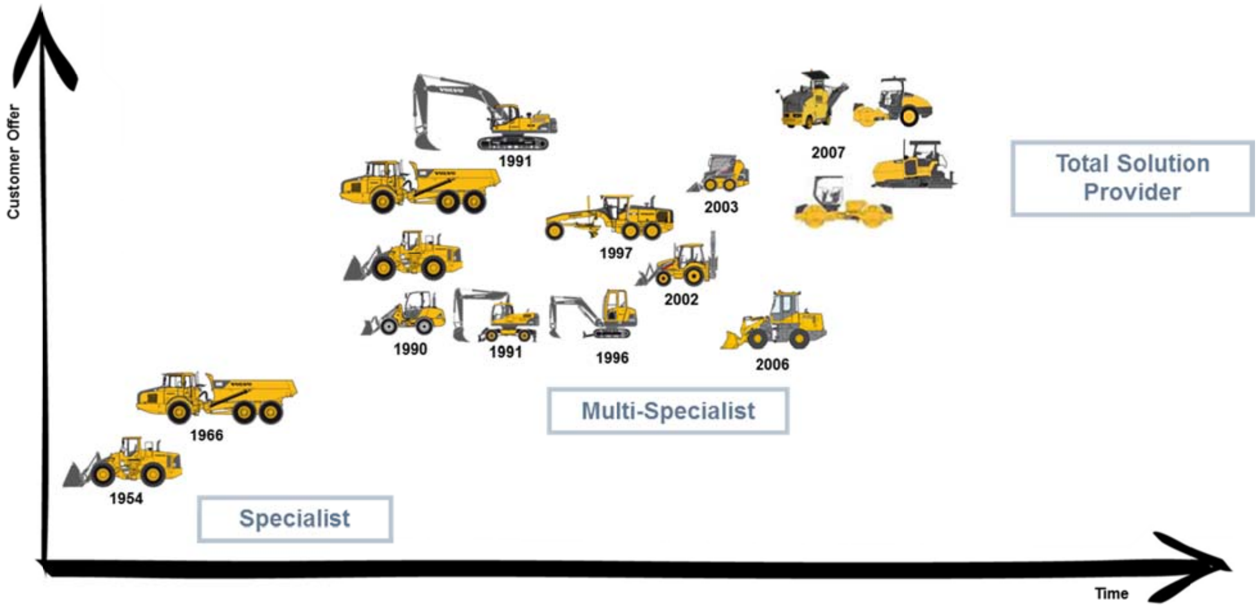


Figure 1: VCE History (Source: VCE)

As of Dec 2013, VCE offers nearly 210 different machines (Source: VCE). To support these machines there are many part numbers which adds complexity in many areas of the companies like the advanced engineering, operations, technology platform, product design, product platform, product planning, purchasing, sales and marketing, etc. Global manufacturing adds another level of complexity to the existing problem diminishing design quality and increasing time to market (Gokpinar et al. 2013).

One of the preferred solutions to the above challenge is to develop a modular architecture for different components which will help in increasing the number of common parts and at the same time offer a wider product range.

The 3DX platform from Dassault Systemes is used to document the modular solutions, Dassault Systemes is a world leader in 3D and Product Lifecycle Management (PLM) solutions. The 3DX platform offers a unique digital product experience that brings 3D product design to life with unmatched realism and delivering collaborative PLM solutions.

1.2 AIM & PURPOSE

In order to reduce the amount of part numbers and to offer a wider product range, a Common Architecture and shared technology (CAST) strategy has been adopted by VCE. The main purpose of the study is to define a Modular architecture, as a technical solution, for hoods. The product categories that are included in the study are Articulated Haulers, Wheel Loaders, Soil Compactors, Backhoe Loaders and Motor Graders.

The study includes the following tasks

- Functional decomposition of the hoods and its associated components
- Benchmarking various modular designs
- Designing and documenting a modular architecture
- Identifying allowed/rejected combination of parts based on design criteria and technical feasibility which enables the creation of better product architecture

The secondary objective of the project would be to test run the modular architecture of the hood on Dassault System's 3DX platform. This requires understanding of CATIA and ENOVIA environment and also the configuration engine which controls the variant management (Baldwin & Clark 1997).

1.3 SCOPE

The Scope of the project has two dimensions. One would be the definition of the modules, the design rules, performance steps and technical feasibility of different components. The second dimension of the project would be to test run the modular architecture on the 3D experience platform which involves the following activities

- Creation of modules in CAD and synchronizing with 3DExperience platform
- Capturing the customer requirements, design criteria and the technical feasibility in 3DExperience platform
- Defining the variant rules and configuration in 3DExperience platform
- Demonstration of the software's capabilities

The product categories and their respective models which will be covered under the study are shown in Table 1. Models are grouped based on commonality of hoods.

Table 1: Product Categories and Models

Product Categories	Models
Articulated Haulers	A25G/A30G
	A35G/A40G
Compact Wheel Loaders	L20F
	L30G
	L45G/L50G
General Purpose Wheel Loaders	L60H/L70H/L90H
	L110H/L120H
	L150H/L180H
	L220H/L250H
Motor Graders	G930C
	G940C/G946C/G960C
Backhoe Loaders	BL60B-BL70B
Soil Compactors	SD25
	SD45
	SD70
	SD75
	SD115-SD135
	SD105-SD130-SD160-SD190-SD200

1.4 LIMITATION

The Scope of the project will be limited to only the above mentioned five product categories due to the possible synergies that were identified before the start of the project. The number of product categories might go down if the study reveals there is less synergy between them. The business case in the CAST methodology is limited to the high level due to the time constraints. The design phase would be limited to modeling the parent level parts only (panels) and would not be concentrating on the finer details.

1.5 DELIVERABLES

The Deliverables out of the study is mentioned below

- A modular architecture design for the hood and its interfaces (Module and Interface definition)
- Requirements and technical feasibility definitions
- CAD models of modules and interfaces in CATIA V5 and CATIA V6
- Performance step definition
- A video of the variant management and modular definition for the modular hood in 3DExperience Platform
- A masked report agreed upon by VCE and DS for public use

2. NEEDS MAPPING

This chapter describes the various phases involved in the mapping of needs in order to define an efficient product architecture. The different phases are described below

2.1 DATA COLLECTION METHODS

Data collection for the project was done using the following methods

2.1.1 LITERATURE STUDY

In order to establish a modular product architecture, it is necessary to identify the relationship between function and design. Various internal documents from VCE were studied in order to understand the different product categories and their product structure.

VCE's product catalogues were studied in order to understand the specifications and the features of the different products.

The modular architecture defined for the cab was used as an example. The relationships between the requirements and design were clearly mapped for the modular cab and were available from the beginning of the project for reference.

2.1.2 INTERVIEWS

Interviews were conducted with different stakeholders in order to identify the various requirements. Interviews were in the form of

- Online meetings
- Personal interviews

Online meetings were mainly done to collaborate with specialists in hood design who are outside Sweden. Personal meetings were one-on-one face to face interviews conducted in both Eskilstuna and Braås (Wheel Loaders and Articulated Haulers) in Sweden. The questionnaires used for the interview and the list of interviewees are attached in the Appendix I.

Since the project captures the requirements directly from the engineers, for this study the need to explore on the marketing requirements is subsided.

2.2 ESTABLISHING REQUIREMENTS STRUCTURE

The output of the literature study and the interviews were unstructured and it needed to be structured in order to identify the synergies between different requirements and its impact on design. The requirements captured for each and every model for all the five product categories were categorized under two dimensions. The generic requirement structure covers the basic requirements the design of the hood needs to satisfy and the feature based requirement structure explains about the features which drives the design of the hood.

2.2.1 GENERIC REQUIREMENT STRUCTURE

The generic requirement structure categorized the products from the functional point of view. There were both internal and external requirements which need to be satisfied for the product to be successful. The requirements were captured under two main categories

- Design Requirements
- Legal Requirements

The classification of the requirements is limited to the above mentioned requirements as the requirements were captured from the engineers directly.

Design Requirements

Design requirements in this context cover all requirements related to the advanced engineering, operations, technology platform, product design, product platform, product planning, purchasing, sales and marketing, etc. The design requirements are further broken down to a level until it can be quantified. The breakdown of the design requirements is shown in Figure 2.

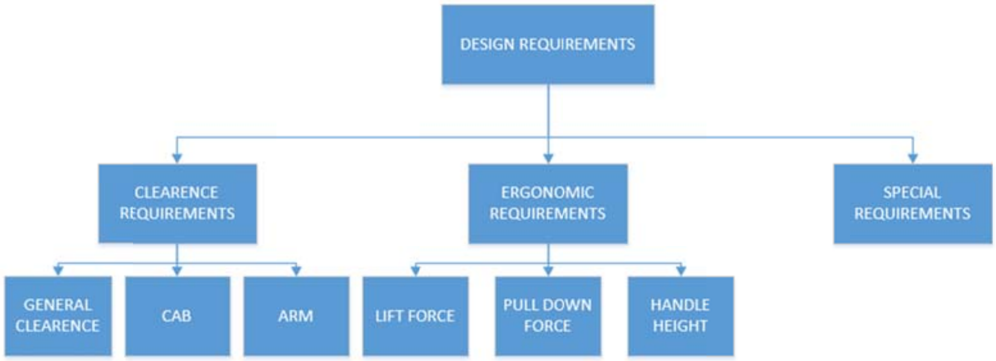


Figure 2: Functional Breakdown of the requirements

Clearance requirements

Clearance requirements describe the general clearance required between the hood and the internal components. Even though the precise distance cannot be mentioned for all the components, a macro level clearance requirement is described. Clearances include both static and moving components. All the components which influence the hood design such as the cab and boom arm are also taken into account.

Ergonomic requirements

Ergonomic requirement refers to the manual efforts required to operate the hood in the case of hoods which needs to be raised manually. It also describes the maximum height allowed for the hood handle in its open condition.

Special requirements

Special requirement refers to those requirements which are unique to specific product categories. Examples of special requirements may be sealing requirements or vibration handling requirements etc.

Legal requirements

The design of the hood is constrained only by two regulations.

Visibility requirements

Visibility in construction equipment is of topmost importance when it comes to the safety of both the driver and the pedestrians. Blind spot accounts to nearly 50% of fatalities related to construction equipment accidents (Hinze & Teizer 2011). The visibility requirement for the entire vehicle is governed by ISO 5006:2006 (Figure 3) for all the product categories under study. The standard requires a visibility of objects at a height of 1.5m at a distance of 1m from the extremity of the vehicle.

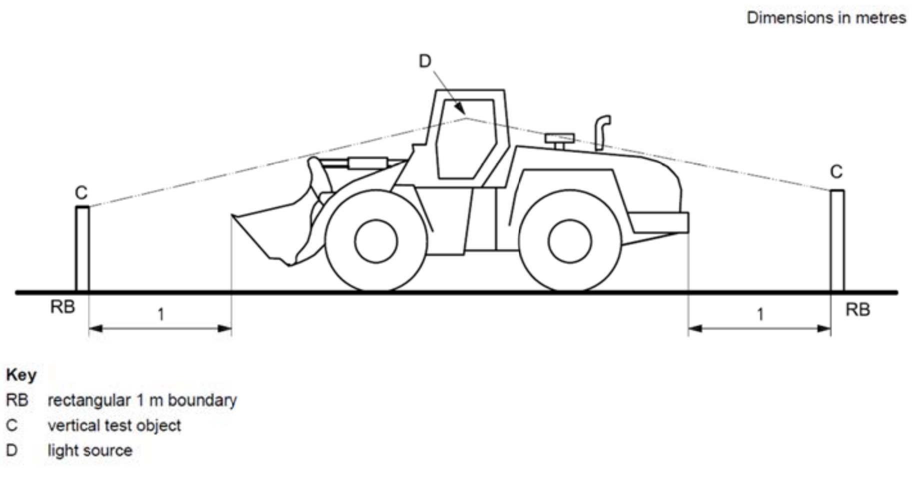


Figure 3: Visibility Requirement for construction vehicles (Source: ISO 5006)

Wind speed Requirement

Wind speed Requirements states the condition (wind speed) in which the hoods of construction vehicles needs to be open without closing automatically. The wind speed requirements are summarized in Appendix II.

2.2.2 FEATURE BASED REQUIREMENT STRUCTURE

This structure describes the physical features in the hood which supports the overall functioning of the vehicle. This structure plays an important role in defining the configuration features and the technical rules in the 3DX software.

Classification of the features is done with respect to three criteria.

Opening of Hood with respect to cab

Engine Inlet/Exhaust

Cooling Inlet/Exhaust

The selection of features is limited to the macro level due to the reason that all the other physical features are dependent on these three factors.

Opening of Hood with respect to the cab

Opening of hood with respect to the cab is very critical when it comes to the positioning of hinges, latches and the design of the hood itself. Opening of the hood towards the cab has advantages of easy accessibility to the radiator but cannot be tilted more than 100° as it will interfere with the cab. One more problem with having the hood tilt towards the cab is that, the overall height of the vehicle increases for longer hoods making it impossible to service cabs inside workshops.

On the other hand opening of the hoods away from the cab helps easier opening of long hoods inside workshops. A proposal is made for L60H to position the hood in such a way that it opens away from the cab.

Engine Inlet/Exhaust

The hood provides the necessary provisions for holding engine inlet and exhaust stacks. The engine inlet is usually placed on the side panels for most vehicles but also on the top for a few. The engine exhaust for most of the vehicles is on the top panel. Some vehicles do not have the exhaust stack on the hood (see Figure 4).

Figure 4: Hood Inlet/Exhaust

Cooling Inlet/Exhaust

The hood plays an important role in providing inlets and exhausts for the cooling system. The grille helps in channeling the air either towards or away from the cooling system and has a direct impact on the performance of the vehicle.

2.3 MAPPING REQUIREMENTS

Based on the various interviews from the design specialists and the requirement structure, the captured requirements can be broken down and allocated to the different features and parts. After identifying the common and unique functions, configuration rules can drive the selection of the features (Dahmus et al. 2001). A complete summary of the mapped requirements is attached in Appendix II. The mapping of the feature based requirements is summarized in Figure 5.

CATEGORY	MODEL	ENGINE	HOOD OPENING W.R.T CAB		AIR INTAKE			EXHAUST			COOLING INLET				COOLING EXHAUST		
			TOWARDS	AWAY	LH	TOP	RH	LH	TOP	RH	FRONT	LH	TOP	RH	LH	TOP	RH
SOIL COMPACTORS	SD75	D3.8	X			X			NA		X					NA	
	SD115	D4/D6	X			X			NA		X					NA	
BACK HOE LOADERS	BL60B-BL70B	D3	X			X			X		X					NA	
GENERAL PURPOSE WHEEL LOADERS	L60H-L90H	D6		X	X				X		X	X		X		X	
	L110H-L120H	D8		X	X				X		X	X		X		X	
	L150H-L180H	D13		X	X				X		X		X		X		X
	L220H-L250H	D13		X	X				X		X		X		X		X
COMPACT WHEEL LOADERS	L20F-L25F	D3	X			X			X		X		X		X		X
	L30G-L35G	D3	X			X			X		X		X		X		X
	L45G-L50G	D4	X			X			X		X		X		X		X
MOTOR GRADERS	G930C	D8	X			X			X		X		X		X		X
	G940-G960C	D9	X			X			X		X		X		X		X
ARTICULATED HAULERS	A25F-A30F	D11`	X			NA			NA		X				X		X
	A35F-A40F	D13/D16	X			NA			NA		X				X		X

Figure 5: Feature based requirement mapping

2.4 FUNCTIONAL BREAKDOWN

In order to allocate the requirements to different parts and quantify the requirements, it is necessary to functionally breakdown the hood. The hood in itself has a clear top level breakdown which is common for both design and manufacturing. The hood can be clearly broken down into five main segments (See Figure 6)

- Front Panel (Grille)
- Left Hand panel
- Right Hand Panel
- Top Panel
- Hood superstructure and associated mechanisms (Hinges, Latches, etc.)

All the features and requirements captured from the different interviews can be allocated to the above mentioned panels.

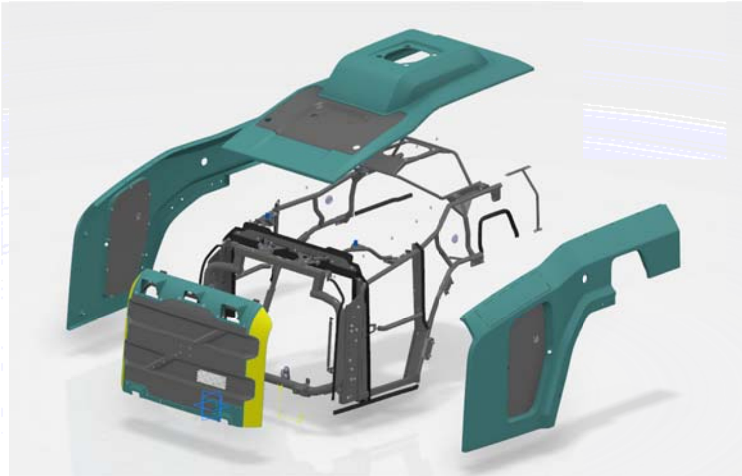


Figure 6: Functional Breakdown of hood

In order to avoid the confusion in the nomenclature of the modules of the grille due to the difference in orientation between different vehicles (Figure 7), the general description of the hood is described as mentioned in Table 2. Irrespective of the position of the hood in the vehicle, the grille mesh is always referred as the front of the hood. A generic nomenclature is used in order to avoid confusions due to multiple descriptions for the same panel.

ENGINE IN THE FRONT OF VEHICLE	ENGINE IN THE REAR OF VEHICLE
	

Figure 7: Engine Position in vehicle

Table 2: Hood Nomenclature

General Description	Position of hood	Front of the hood refers to	Left hand side of the hood refers to	Right hand side of the hood
Articulated Hauler	Front of the vehicle	Front of the vehicle	Left hand side of the vehicle	Right hand side of the vehicle
Wheel Loaders	Rear of the vehicle	Rear of the vehicle	Right hand side of the vehicle	Left hand side of the vehicle
Backhoe Loader	Front of the vehicle	Front of the vehicle	Left hand side of the vehicle	Right hand side of the vehicle
Motor Graders	Rear of the vehicle	Rear of the vehicle	Right hand side of the vehicle	Left hand side of the vehicle
Soil Compactors	Rear of the vehicle	Rear of the vehicle	Right hand side of the vehicle	Left hand side of the vehicle

2.5 INTERFACE ANALYSIS

In order to understand the relationship between the design of the hood and the surrounding components, a table is mapped to show the relationship. The level of detail is kept to a minimum with respect to the relationship between the design of the hood and the interface indicating only whether there is an impact on the hood if the design of the interfaces is changed. The relationship is summarized in Appendix II.

3. CONCEPT DEVELOPMENT

This chapter explains the process of concept development from the requirements. The flow of the chapter follows a uniform structure where the methodology is discussed first followed by the concept generation, concept evaluation ending in the product architecture definition.

3.1 CONCEPT DEVELOPMENT METHODOLOGY

There are two methods which are applied in this project. One is the generic process followed and the other is the modular design process of VCE.

3.1.1 GENERAL METHODOLOGY

The general approach to the overall project follows the generic product development strategy (Figure 8) defined in Product Design and Development (Ulrich & Eppinger 2012).

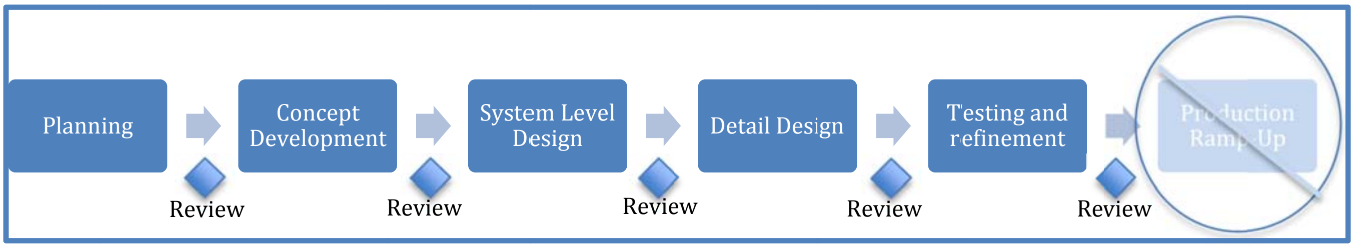


Figure 8: Generic Product Development Process (Ulrich and Eppinger, 2012)

Production ramp up is not included in the scope of the project. Both the hardware and software definition are encompassed into the above mentioned product development process.

3.1.2 MODULAR ARCHITECTURE DEFINITION PROCESS

To define the modular architecture, Volvo's internal methodology (Figure 9) is used. The process is divided into six steps which is shown below.

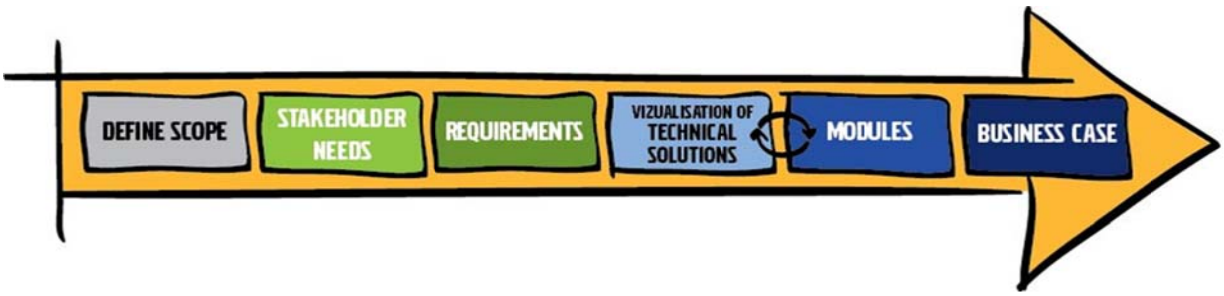


Figure 9: Volvo CE Modularisation method (Source: VCE)

Step 1: Define Scope

Scope definition plays an important role in determining the complexity of the modules. It is important to make a conscious choice on what to include and what not to include. As this project serves as a prestudy for future products, modules are limited to their top level only.

Step 2: Stakeholder needs

The needs of all the stakeholders needs to be captured. Stakeholders may be advanced engineering, operations, technology platform, product design, product platform, product planning, purchasing, etc. The products entire lifecycle needs to be taken into account and the synergies needs to be identified. It is necessary to create a balance between the needs so that an optimum architecture can be designed. Since the project serves as a prestudy the main stakeholder would be the designers of the current product categories and the existing design.

Step 3: Requirements

The needs given by the different stakeholders have been expressed in different ways. These have to be converted into a common technical specification with requirements that can be understood by the engineers. Requirements can either be functional, logical, physical or a combination of the above three.

Step 4: Visualization of technical solutions

This is the first step to create the product architecture and hence identifying the modules and interfaces. This is mainly done so that none of the requirements are forgotten. Concept sketches are created without much details in this step.

Step 5: Finding the Modules

The key to modularity is to find patterns cross a product range. Patterns show us what can be common and what has to be unique for each variant. The solution is to identify common as well as unique requirements. This involves three steps

- Identifying common solutions
- Identifying unique solutions
- Identifying performance steps

Step 6: Business Case Verification

This step will help in veryfying the business case and answering certain questions like Does the product meet the cost targets?

Does the architecture meet the requirements of the products?

Is the modular design cheaper than the integral design ?

What is the effect on weight, quality and productivity ?

3.2 CONCEPT GENERATION

Concept generation is an important step in the product development process where the various inputs collected from different stakeholders are converted into a more useful product (Ulrich & Eppinger 2012).

3.2.1 SHAPE DRIVERS

In order to identify the dimensional constraints of design, a study was conducted to identify different factors which affect the shape of a hood. Even though the shape of the hood is driven by styling, engineering constraints too drive the shape of the hood. The concept behind zone definitions is based on the limits up to which a cluster of components drive the design of the panel. For example, in Wheel Loaders, the cooling package drives the size of the panels in and around the radiator grille but has no significant impact on the design of the panels surrounding the engine. This helps to seperate the engine bay into different zones. Constraints from all directions to the dimensions of the hood are analyzed in order to efficiently compare between different product categories.

Wheel Loader

The shape of a Wheel Loader hood is more of a “bean bag shape” when viewed from the top. This has a negative effect on the ease with which it can be modularized.

Wheel Loader Zone Definition

In order to define the dimensional constraints at different parts of the hood, the entire hood is divided into different zones as shown in Figure 10 and Figure 11. The various dimensional constraints for different zones are summarized in Table 3 for the Wheel Loaders.

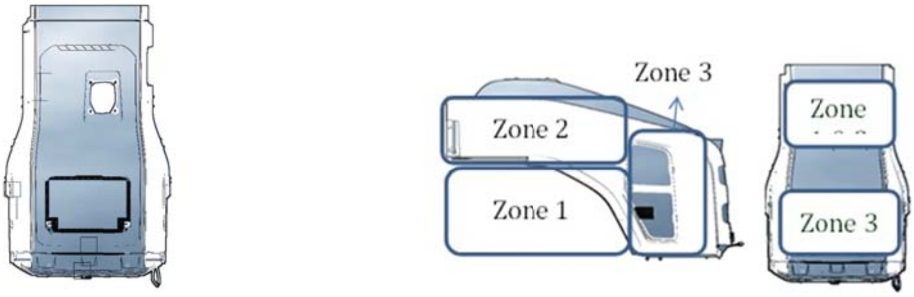


Figure 10: Wheel Loader Top View (Left) Zone Definition (Right)

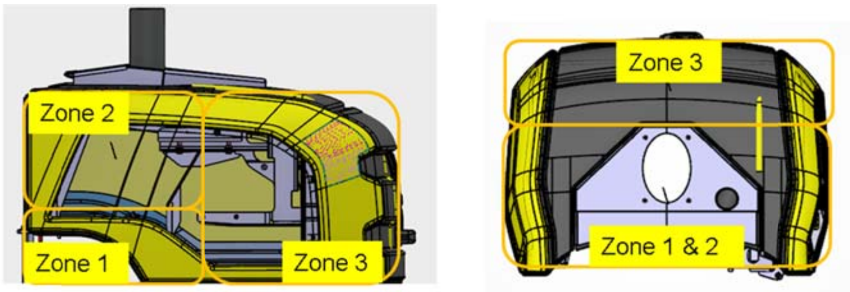


Figure 11: Compact Wheel Loader – Zone Definition

Table 3: Summary - Zone Definiton – Wheel Loaders

Zones	Description	Constraints - Exterior	Constraints - Interior	Can be changed?
Zone 1	Area beneath the fender	Wheel Envelope	Engine	No – Gap between the wheel envelope is minimum
Zone 2	Area around the after treatment	Visibility of Counter weights	Exhaust treatment system	No – Gap between the exhaust system and the hood is optimum
Zone 3	Area around cooling system	Visibility	Cooling package	No – Gap between the cooling package and hood is minimum

Observations

Some of the observations from Table 3 are listed below

- Wheel Loaders are constrained mainly by visibility regulations governed by ISO 5006 and visibility towards the counterweights
- The length of the hood cannot be increased because of overhang issues and its effect on the turning radius. The distance between the counterweights and the rear axle is one of the main unique selling points (USP) for VCE which helps in maneuvering the vehicle easily

Soil Compactors

Soil Compactors have a unique design when compared to the other vehicles within VCE. An additional vibrational load of 45HZ is encountered by the components of the vehicle along with the operational load. The radiators are present at an inclined angle, which is due to the steep inclination of the hood. The steep inclination of the hood is to satisfy the 1m X 1m visibility requirement (see Figure 12) which is an USP of VCE (1m X 1.5m is the legal requirement).

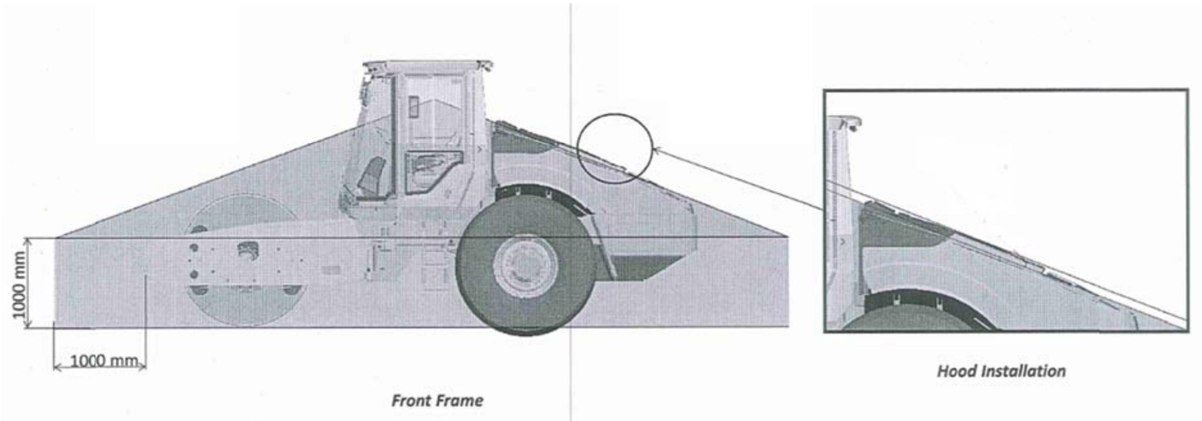


Figure 12: Soil Compactors – Visibility Zone

Soil Compactors Zone Definition

The zone definition of Soil Compactors is described in Figure 13 and summarized in Table 4.

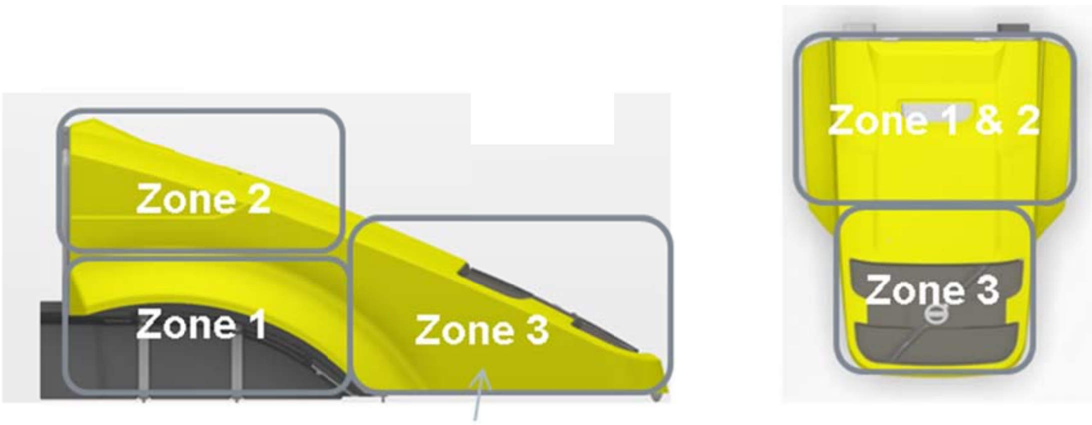


Figure 13: Soil Compactors – Zone Definition

Table 4: Summary - Zone Definiton – Soil Compactors

Zones	Description	Constraints - Exterior	Constraints - Interior	Can be changed?
Zone 1	Area beneath the fender	Wheel Envelope	Engine	No – Gap between the wheel envelope is minimum
Zone 2	Area around the air intake	Visibility, USP of 1m X 1m	Air Intake system	Yes – If cost benefit is substantial compared to USP
Zone 3	Area around cooling system	Visibility, USP of 1m X 1m	Cooling package	Yes – If cost benefit is substantial compared to USP

Observations

- The design is driven mostly by the USP of 1m X 1m. The entire engine bay is constrained by the USP requirement.
- The absence of the exhaust system on the top gives a rather smooth top panel similar to an Articulated Hauler

Articulated Haulers

Articulated Haulers are characterized by their unique slim waist design to maximize visibility and ground clearance. The cooling fans are on the sides to suit this design. The top panel is smooth due to the absence of the engine inlets and exhausts. It can be compared to the top panel design of Soil Compactors.

Articulated Hauler Zone Definition

The zone definition of Articulated Haulers is described in Figure 14 and summarized in Table 5.

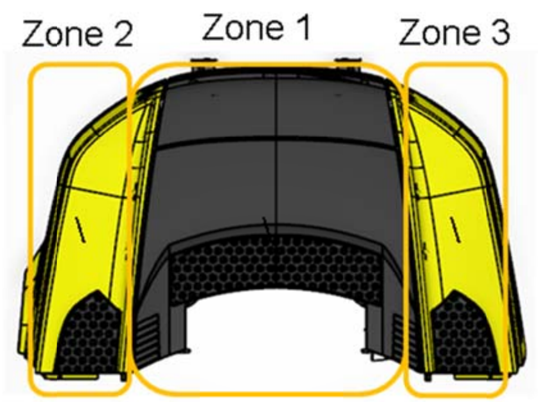


Figure 14: Articulated Haulers - Zone definition

Table 5: Summary - Zone Definiton - Articulated Haulers

Zones	Description	Constraints - Exterior	Constraints - Interior	Can be changed?
Zone 1	Area beneath the engine	Wheel Envelope	Engine	Yes - Top of hood can be modified as it is elevated for flush fit with cab
Zone 2	Area around the radiator	Visibility	Cooling system	No - Width cannot be increased due to visibility requirements
Zone 3	Area around radiator	Visibility	Cooling system	No - Width cannot be increased due to visibility requirements

Observations

- Height of the hood can be altered due to the fact that the top sills are elevated to match with the cabs width and can be modified to suit the modular requirements
- Width of the hood cannot be increased compared to the current design as it may decrease the visibility and violate legal requirements

Motor Grader

The hood of Motor Graders which is taken into the study consists of only the frontal portion of the entire hood. The reason for not considering the middle section of the hood is due to the fact that the middle section requires gull wing type doors to access the engine bay whereas the radiator requires a hinge door opening away from the cab. This is due to the fact that the middle section of the engine bay needs to be accessed from the sides.

Motor Grader Zone Definition

Since the design of the front section of the hood is dependent on the radiator, the entire zone definition is limited to one. The zone definition of Motor Graders is described in Figure 15 and summarized in Table 6.

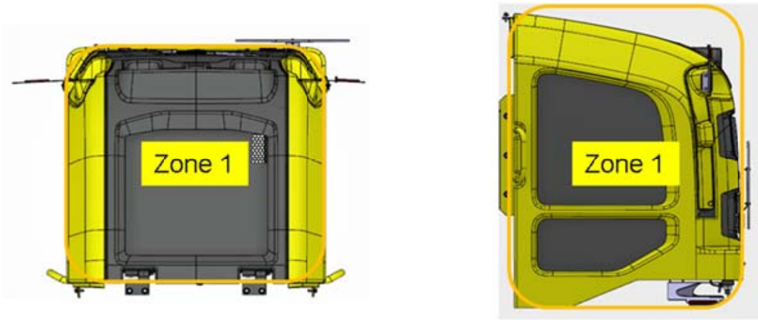


Figure 15: Motor Grader - Zone Definition

Table 6: Summary - Zone Definiton – Motor Graders

Zones	Description	Constraints - Exterior	Constraints - Interior	Can be changed?
Zone 1	Area beneath the Radiator	Visibility, Arm travel	Radiator	No – Dimensions are optimized between visibility and dimensions of radiator and arm.

Observations

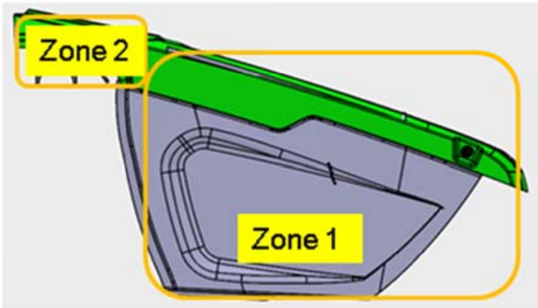
- The width of the hood cannot be increased due to the negative effect on visibility and interference with the arm travel. The height cannot be increased due to the negative effect on visibility
- The side panels have grill mesh covering more than 80% of the area. This can be compared with a Wheel Loader side panel

Backhoe Loader

The dimension of the hood is constrained by the arms of the boom and plays a major role in the design of the Backhoe Loader hood. Visibility and size of the engine are the other factors which affects the design.

Backhoe Loader Zone Definition

The zone definition of Backhoe Loaders is described in Figure 16 and summarized in Table 7.



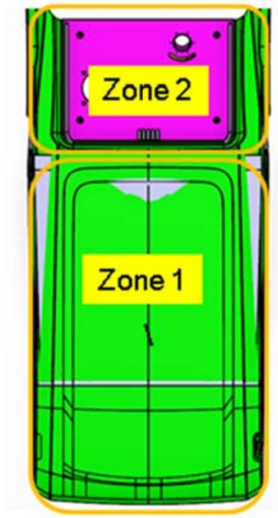


Figure 16: Backhoe Loader - Zone Definition

Table 7: Summary – Zone Definition Backhoe Loader

Zones	Description	Constraints - Exterior	Constraints - Interior	Can be changed?
Zone 1	Area around the engine and radiator	Boom Arm, Visibility	Engine and radiator	No – Width of boom arm hinge is fixed. Any changes would have a ripple effect and increase in height would affect visibility
Zone 2	Area around the engine and the exhaust treatment system	Boom Arm, Visibility	Engine and the exhaust treatment system	No – Width of boom arm hinge is fixed. Any changes would have a ripple effect and increase in height would affect visibility

Observations

- The width of the hood cannot be increased due to the negative effect on visibility and interference with the arm travel. The height cannot be increased due to the negative effect on visibility
- The side panels and top panels have no openings. The top panel can be compared with the top panel of Soil Compactors and Articulated Haulers

3.2.2 DIMENSION ANALYSIS

The basic functional dimensions which define the hoods are measured from CAD and noted down to identify any dimensional synergies that may exist between them. The dimensions are then compared with each other in order to identify small dimensions which can be negated to define common modules. The dimensional comparison is done for all the models in the study. The dimensions are limited only to a few basic dimensions which drive the shape of the hood.

Wheel Loader

The Wheel Loaders hood has eight different dimensions which control its shape. The dimensions which are taken into account are listed below

- a - Width near the radiator in mm
- b - Width near the engine in mm
- c - Overall length in mm
- d - Distance between rear end and exhaust opening (min) in mm
- e - Height of the hood near grille from base plane in mm
- f - Height of the hood near engine from base plane in mm
- g - Overall height of the hood in mm
- h -Height of the rear section of the hood in mm

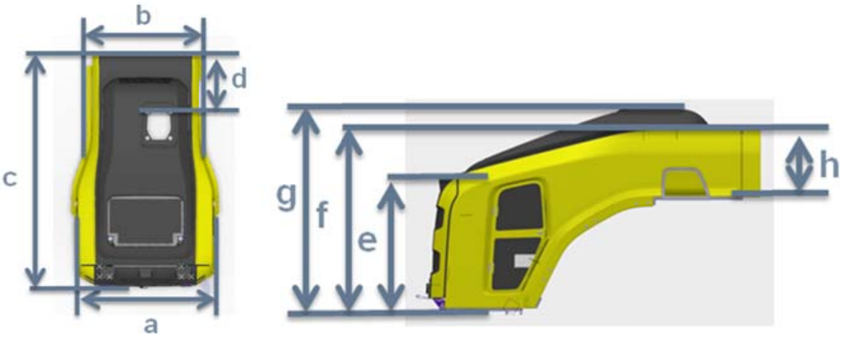


Figure 17: Driving Dimensions – General Purpose Wheel Loaders

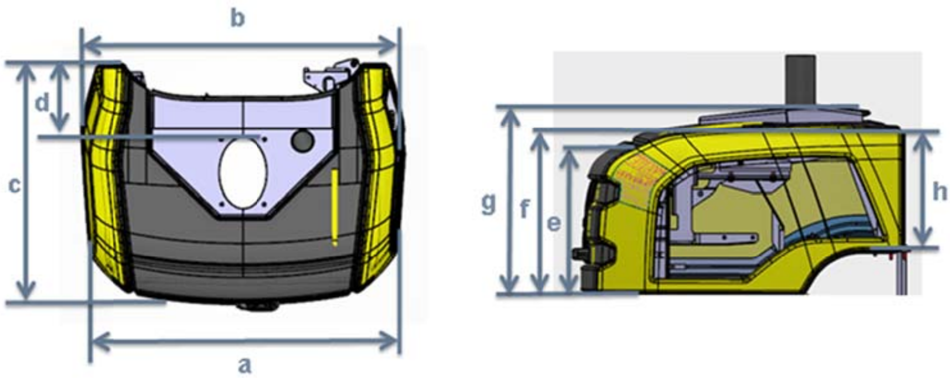


Figure 18: Driving Dimensions – Compact Wheel Loaders

The view on the left side is the top view of the Wheel Loader hood and on the right side is the left hand side view of the hood (Figure 17 and Figure 18). The base plane in the dimensions refers to the plane on which the hood rests on the frame at its closed condition. The dimensions of the Wheel Loaders are summarized in Table 8 and Table 9.

Table 8: Driving Dimensions – General Purpose Wheel Loader

	a	b	c	d	e	f	g	h
L60H	1220	1060	1915	720	980	1360	1430	500
L110H	1550	1280	2625	800	1000	1270	1525	465
L150H	1680	1280	2740	650	1145	1555	1735	590
L220H	1680	1280	2905	820	1145	1555	1735	590

All dimensions are in mm

Table 9: Driving Dimensions – Compact Wheel Loader

	a	b	c	d	e	f	g	h
L20F	1380	1420	1035	400	440	620	630	550
L30G	1420	1310	1080	320	590	560	630	410
L45G	1600	1530	1600	400	580	930	930	410

All dimensions are in mm

A bar graph (Figure 19, Figure 20, Figure 21 and Figure 22) showing the different dimensions helps to visualize the numbers in a more meaningful manner. The synergies between the designs can be easily identified using the graph.

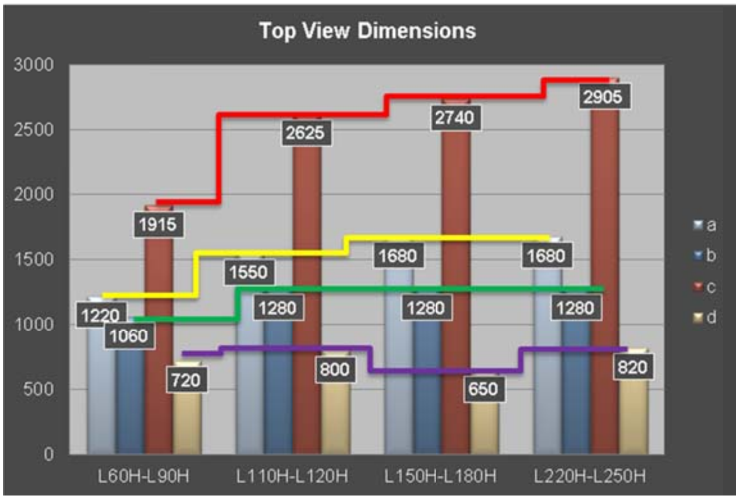


Figure 19: Comparison – Top view dimensions of General Purpose Wheel Loaders

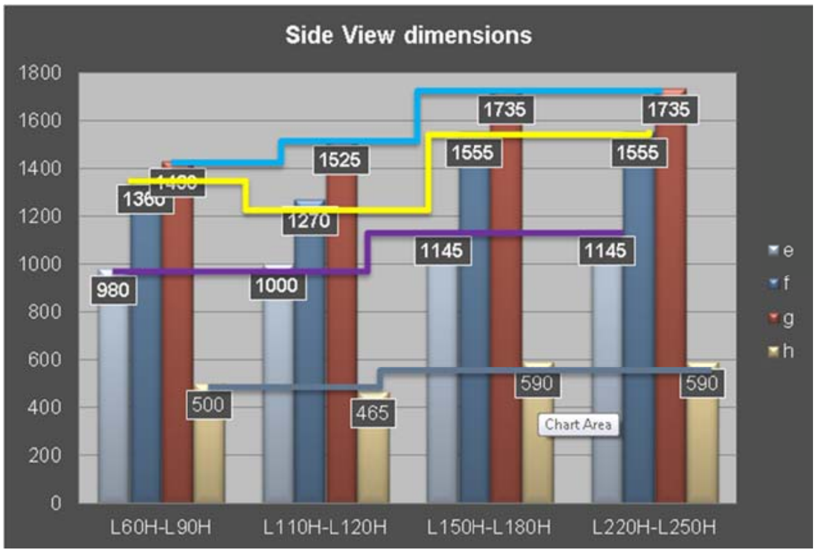


Figure 20: Comparison – Side view dimensions of General Purpose Wheel Loaders

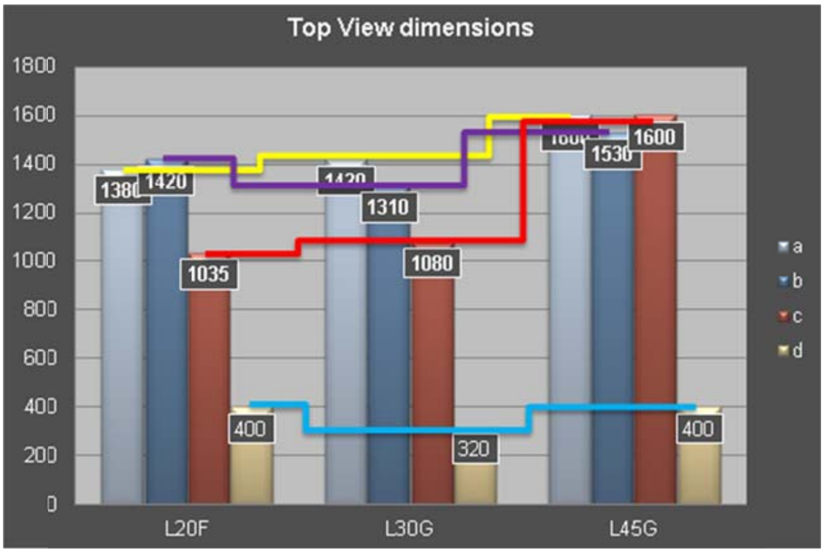


Figure 21: Comparison – Top view dimensions of Compact Wheel Loaders

Figure 22: Comparison – Side view dimensions of Compact Wheel Loaders

Inferences from Wheel Loader graphs explain the inferences linking it to the final product architecture.

- General Purpose Wheel Loaders

  The width of the rear section (b) is common for L120H, L150H and L220H (see Figure 23), resulting in two performance steps on the rear width. The overall height of the front grille (e) has two performance steps (taken care by the grille architecture). The height is common for L60H - L120H and L150H - L220H and the height of the rear section (h) has two performance steps. Side panels can be commonized between the models due to these performance steps.

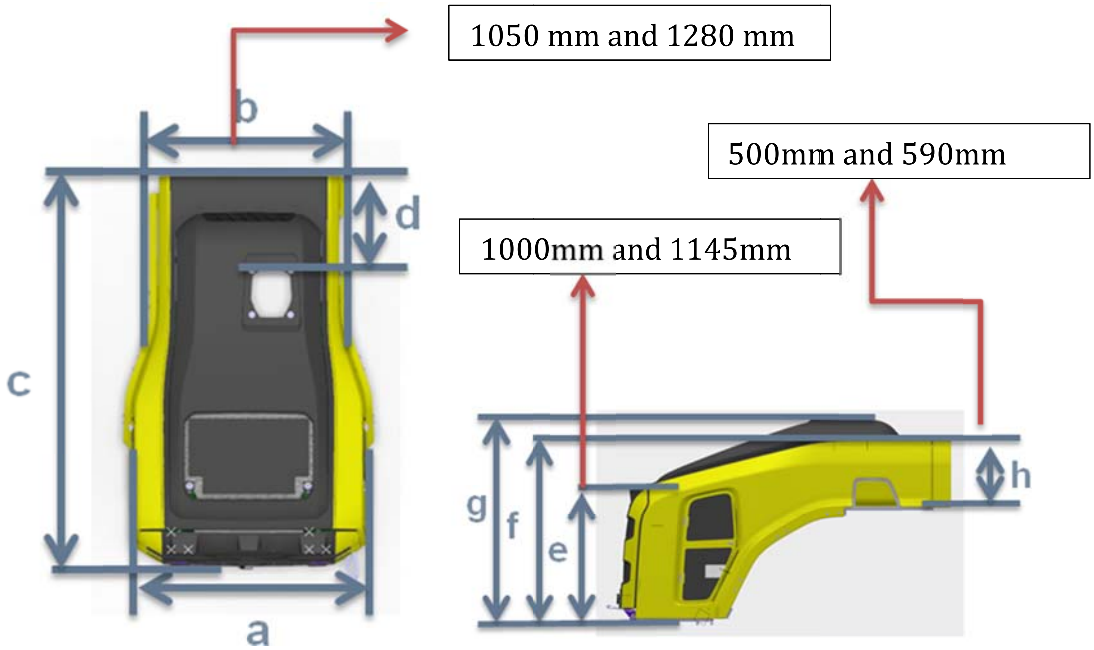


Figure 23: Inference - Wheel Loaders

- Compact Wheel Loaders

  The overall height (e) of the front grille has two performance steps along with the rear section height (h) of the hood (see Figure 24). As a result side panels can be commonized between the two variants.

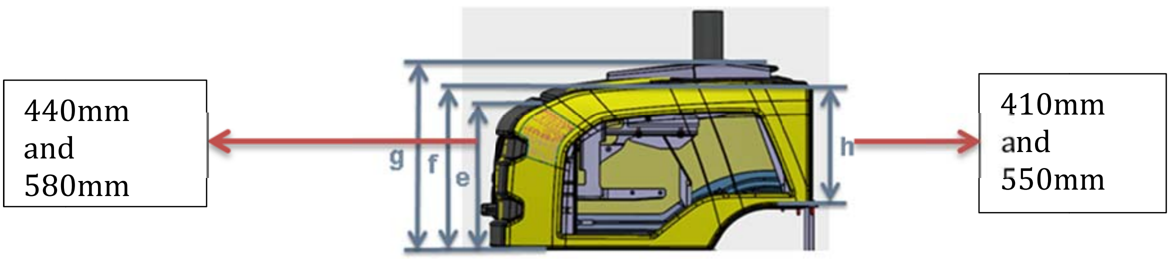


Figure 24: Inference - Compact Wheel Loaders

Soil Compactors

Similar to Wheel Loaders, Soil Compactors also have eight dimensions (Figure 25) that define the boundaries of the hood. The list of driving dimensions is mentioned below

- a - Width near the radiator in mm
- b - Width near the engine in mm
- c - Overall length in mm
- d - Distance between rear end and air intake opening (min) in mm
- e - Height of the hood near grille from base plane in mm
- f - Height of the hood near engine from base plane in mm
- g - Overall height of the hood in mm
- h - Height of the rear section of the hood in mm

The values of the dimensions are summarized in Table 10.

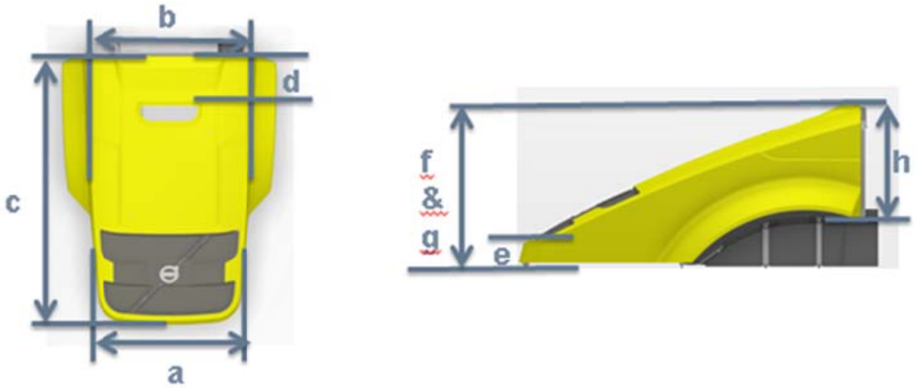


Figure 25: Driving Dimensions – Soil Compactors

Table 10: Driving Dimensions - Soil Compactors

	a	b	c	d	e	f	g	h
SD25	690	865	920	60	650	850	850	685
SD45	710	910	1260	210	700	890	890	890
SD70	970	1300	2020	380	50	930	930	890
SD75	1175	1430	1715	790	125	1000	1000	880
SD115	1180	1420	2235	380	160	1040	1040	750
SD160	1100	1485	2300	540	0	920	920	880

All dimensions are in mm

A bar graph (Figure 26 and Figure 27) showing the different dimensions help to visualize the numbers in a more meaningful manner. The synergies between the designs can be easily identified using the graph.

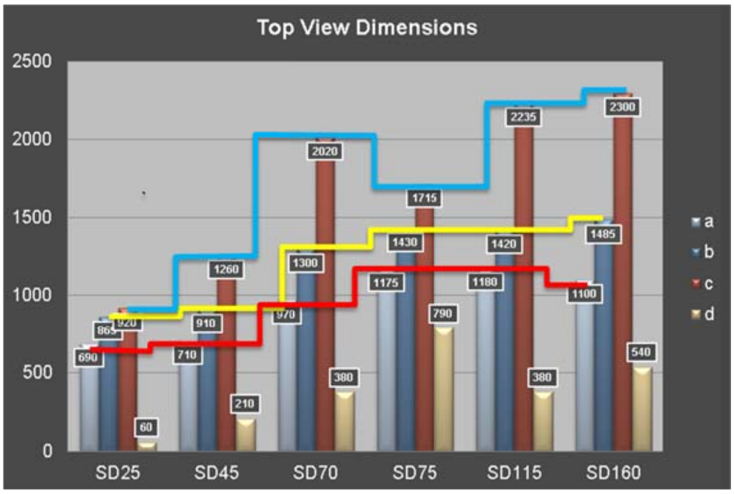


Figure 26: Comparison – Top view dimensions of Soil Compactors

Figure 27: Comparison – Side view dimensions of Soil Compactors

Inferences

The front width (a) and rear width (b) of SD75 and SD115 is the same and the length of the hood (c) varies in two steps (see Figure 28). As a result sections of the hood can be broken down and commonized between models.

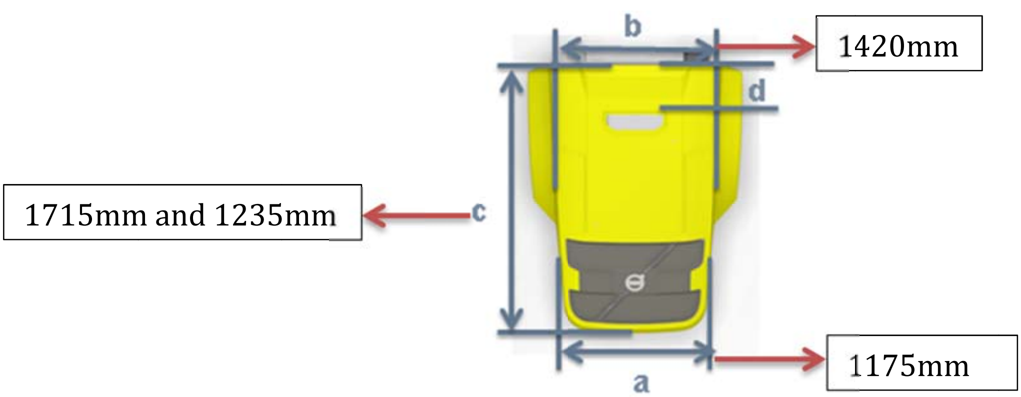


Figure 28: Inferences - Soil Compactors

Articulated Hauler

Due to the absence of inlet or exhaust features on the hood, the driving dimensions are limited to five in an Articulated Hauler. The driving dimensions (Figure 29) are described below

- a - Width near the front in mm
- b - Width near the engine in mm
- c - Overall length in mm
- d - Height of the hood near grille from base in mm
- e - Height of the rear section of the hood in mm

The values of the dimensions are summarized in Table 11.

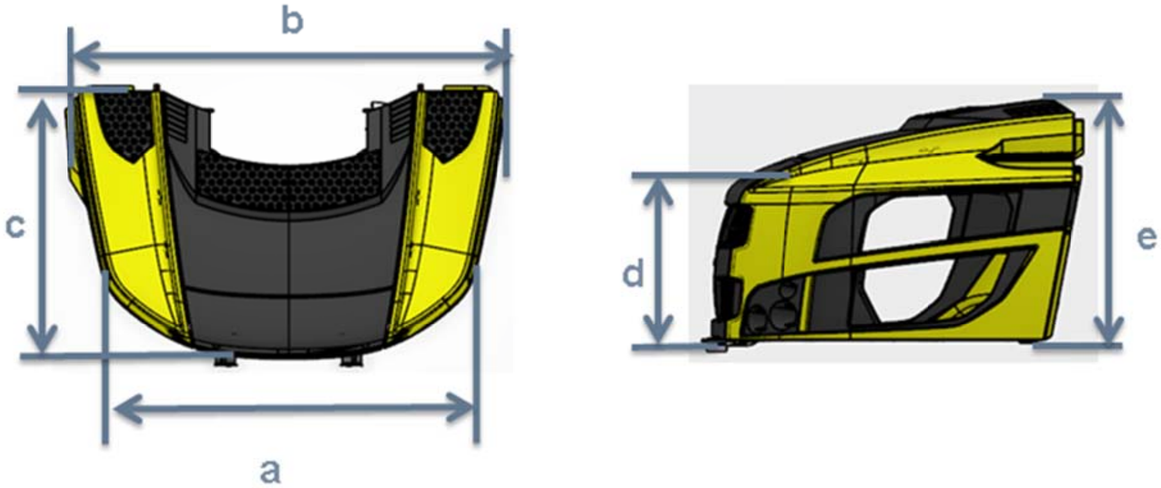


Figure 29: Driving Dimensions - Articulated Haulers

Table 11: Driving Dimensions - Articulated Hailers

	a	b	c	d	e
A20F	2150	2520	1650	680	1080
A40F	1950	2720	1960	720	1450

All dimensions are in mm

A bar graph (Figure 30) showing the different dimensions help to visualize the numbers in a more meaningful manner. The synergies between the designs can be easily identified using the graph.

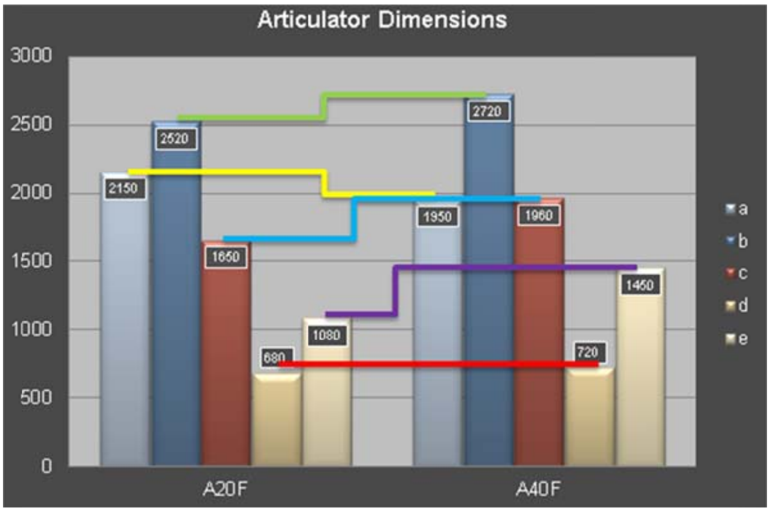


Figure 30: Comparison – Driving dimensions of Articulated Haulers

Inferences
The height of the front grille is common between the two models (see Figure 31). No other commonality can be observed between the two models in any of the dimensions between the models.

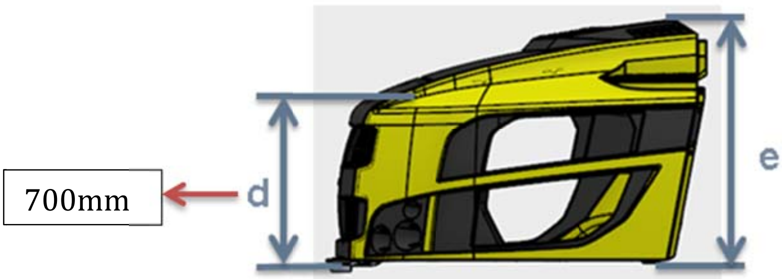


Figure 31: Inferences - Articulated Haulers

Motor Grader
The number of dimension drivers (Figure 32) in the case of Motor Graders is limited to five dimensions due to the fact that only the front section of the entire hood is considered. The dimensions considered are listed below

- a - Width near the front in mm
- b - Width near the engine in mm
- c - Overall length in mm
- d - Height of the hood near grille from base in mm
- e - Height of the rear section of the hood in mm

The values of the dimensions are summarized in Table 12.

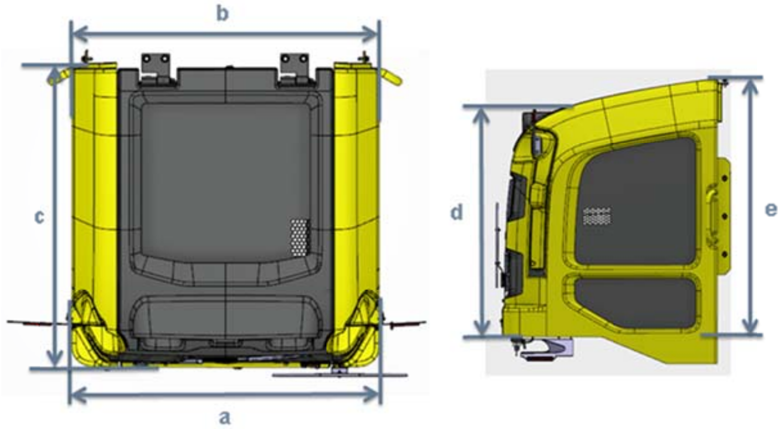


Figure 32: Driving Dimensions – Motor Graders

Table 12: Driving Dimensions – Motor Graders

	a	b	c	d	e
G930C	1020	1020	980	700	1180
G940C	1020	1020	1110	700	1180

All dimensions are in mm

A bar graph (Figure 33) showing the different dimensions help to visualize the numbers in a more meaningful manner. The synergies between the designs can be easily identified using the graph.

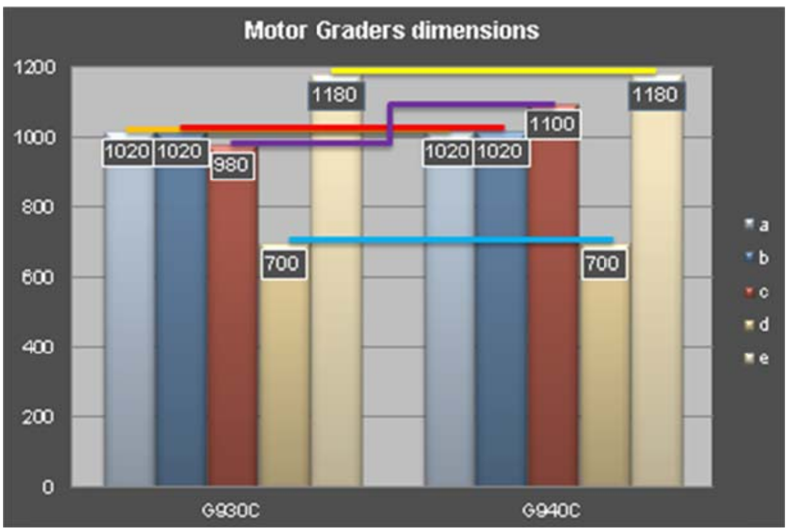


Figure 33: Comparison – Driving dimensions of Motor Grader

Inferences

All the main driving dimensions except the length of the hood are the same. As a result different panels can be commonized accordingly.

Backhoe Loader

All Backhoe Loaders have the same hoods, the basic driving dimensions (Figure 34) is listed below

- a - Width near the radiator in mm
- b - Width near the engine in mm
- c - Overall length in mm
- d - Distance between rear end and exhaust opening (min) in mm
- e - Height of the hood near grille from base plane in mm
- f - Height of the hood near engine from base plane in mm
- g - Overall height of the hood in mm
- h -Height of the rear section of the hood in mm

The values of the dimensions are summarized in Table 13.

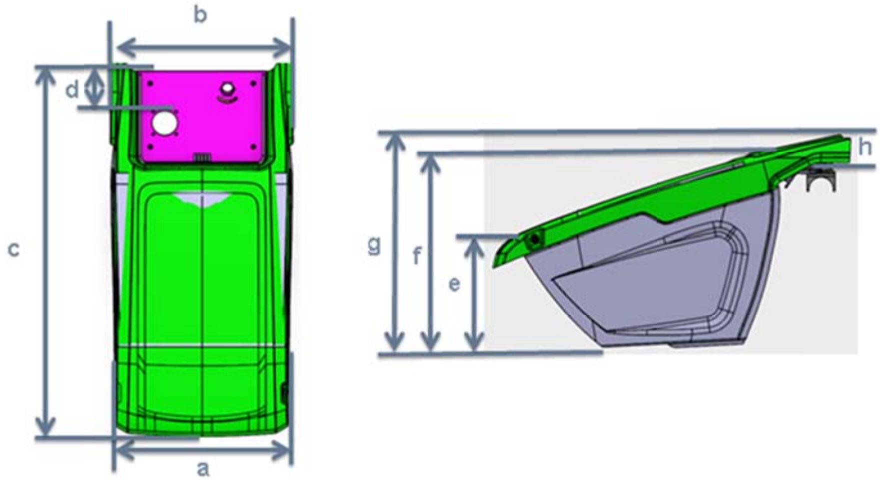


Figure 34: Driving Dimensions – Backhoe Loaders

Table 13: Driving Dimensions – Backhoe Loaders

	a	b	c	d	e	f	g	h
BHL	740	760	1610	210	500	900	960	100

All dimensions are in mm

A bar graph (Figure 35) showing the different dimensions help to visualize the numbers in a more meaningful manner. The synergies between the designs can be easily identified using the graph.

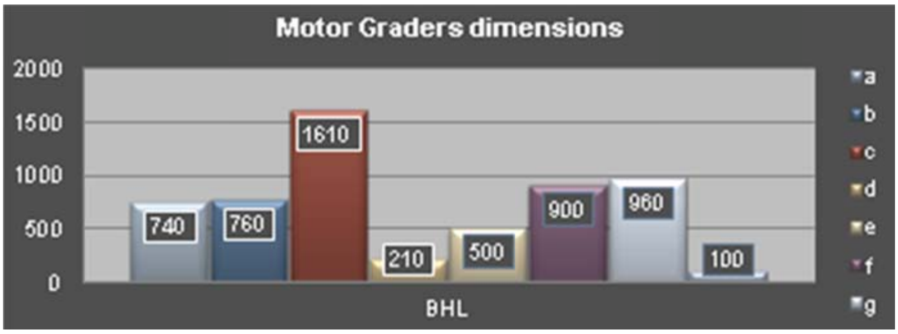


Figure 35: Comparison – Driving dimensions of Backhoe Loaders

Inferences

Since the hood is already common for all the Backhoe Loader models and optimized for different constraints, the study is limited to the commonization of parts only. The top panel of Backhoe Loaders can be compared to the top panel of Soil Compactors but the change in design would increase the part number. The integral design can be retained instead of a modular design.

Grille Dimensions

The grille plays an important role in portraying the design language of Volvo. The four main dimensions (Figure 36) which are taken into consideration is shown below

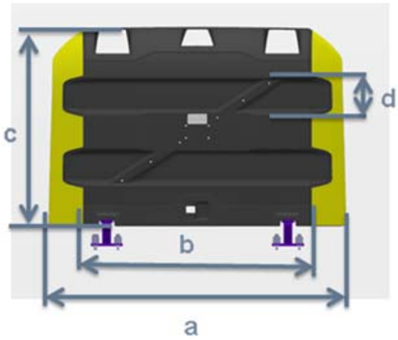


Figure 36: Comparison – Driving dimensions of Front Grille

- a - Width of hood in mm
- b - Width of front mesh in mm
- c - Overall height of hood up to headlamp level in mm
- d - Width of fins in mm

The values of the dimensions are summarized in Table 14

Table 14: Driving Dimensions – Front Grille

	a	b	c	D
L20F	1380	820	440	130
L30G	1420	1020	590	160
L45G	1600	1020	580	130
L60H	1090	860	970	160
L110H	1410	1210	920	175
L150H	1580	1220	1050	180
L220H	1580	1220	1050	180
A20F	1120	1120	680	180
A40F	1120	1120	720	180
G930C	1020	700	1000	180
G940C	1020	700	1000	180

All dimensions are in mm

A bar graph (Figure 37) showing the different dimensions help to visualize the numbers in a more meaningful manner. The synergies between the designs can be easily identified using the graph.

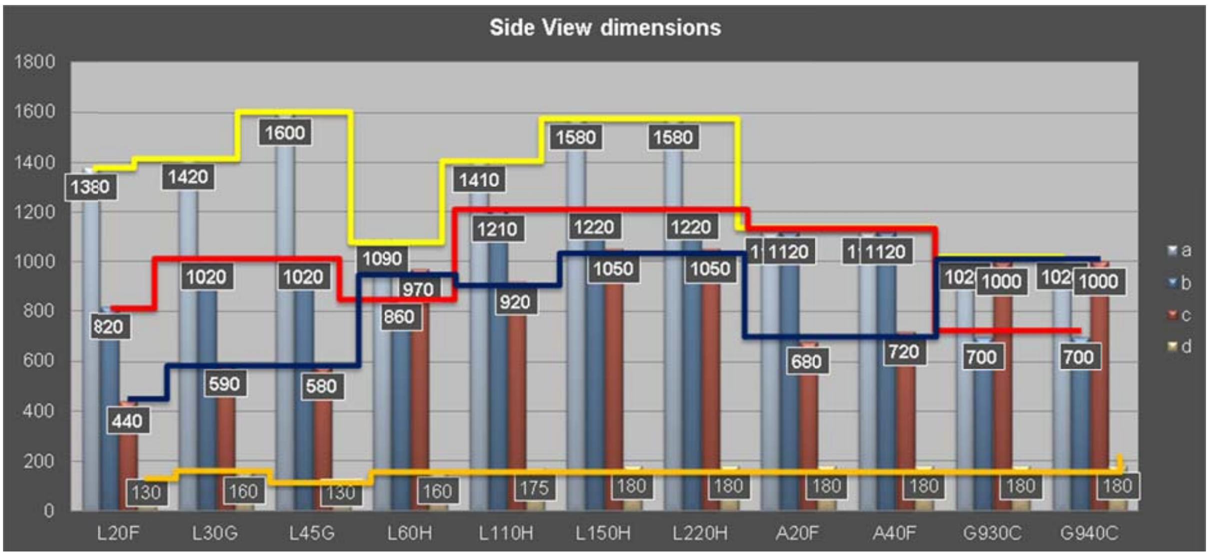


Figure 37: Comparison – Driving dimensions of Front Grille

Inferences

- The distance between the fins (d) in the meshes follows a standard value across all models due to the size of the Volvo logo (see Figure 38)
- The width of the mesh (b) is common for L 120H, L150H and L220H (see Figure 38)
- The width of the meshes (b) is more common than the overall width of the hood. This can help in commonizing the width of the meshes (b) and adding bezels to satisfy the width (a) requirements

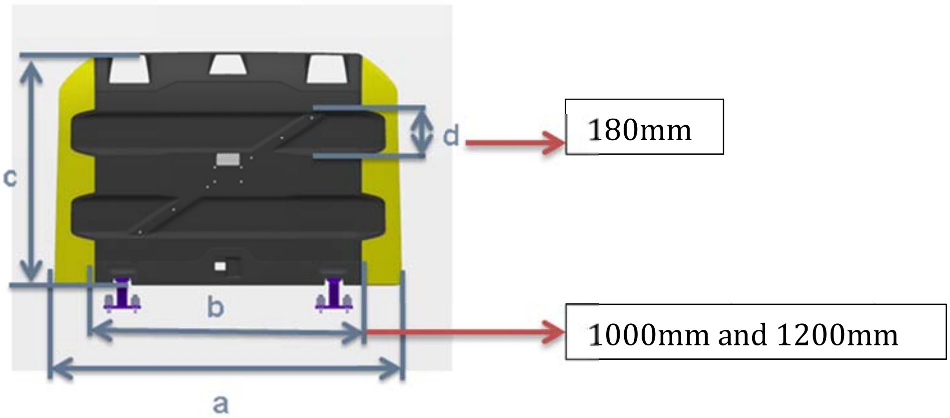


Figure 38: Inferences - Grille

3.2.3 BENCHMARKING

One of the best ways to improvise or find solutions to problem is to learn from others. Knowledge has been gathered in an organization over a period of time through different projects. The learnings from different projects can be applied in future projects thereby effectively reducing resources and time taken to test solutions.

3.2.3.1 INTERNAL BENCHMARKING

Internal benchmarking helps to identify solutions from within the organization. The Modular Cab (See Figure 39) definition was one of the examples used for defining the modular architecture of the hood. Different modules and their interfaces were defined in order to allow possible interchange and reuse of parts.

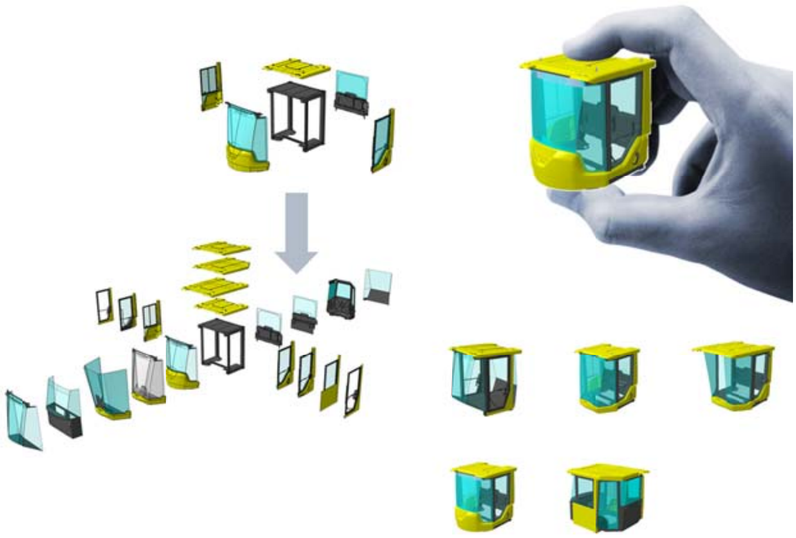


Figure 39: Modular Cab Definition

3.2.3.2 EXTERNAL BENCHMARKING

Knowledge can be gathered from both within and outside an organization. Inspirations for solving the problems can be obtained from competitors designs. Benchmarking the tradeoffs made between the USP and the design solutions can help in decision making.

Wheel Loaders

One of the main competitors for VCE in the Wheel Loader segment is Caterpillar (CAT 2015). The hood design in CAT (Figure 40) follows a more boxy shape; the reason might be due to the fact that the visibility towards the counter weight is not taken into consideration in the case of CAT's design. The position of the engine and cooling exhausts and the intakes resemble VCE's design. Competitors design methodology was not available during the time of the study as a result, only the visual differences were noted as shown in Figure 40 and Figure 41.

Figure 40: CAT Wheel Loaders

Figure 41: Komatsu Wheel Loaders

The design of both Komatsu (Komatsu 2015) and CAT had similarities with respect to the hood except that Komatsu (Figure 41) had limited fillets on the edges whereas CAT had fillets which was comparable to Volvo's Wheel Loaders. Both General purpose Wheel Loaders and Compact Wheel Loaders of the competitors were comparable with each other.

Soil Compactors

The hoods of the Soil Compactors of the competitors are much higher around the radiator. This might be due to the fact that less stringent focus on using visibility as an USP. The general hood design in the competitor's vehicle follows the same design as in Wheel Loaders. The Soil Compactors of CAT and Dynapac (Dynapac 2015) are shown in Figure 42.

Figure 42: CAT Soil Compactors (Left), Dynapac Soil Compactors (Right)

The fillets on the edges of the panels are more smoother on CAT (similar to Volvo) compared to the other competitor vehicles.

Articulated Haulers

The slim waist design of the hood in Volvo is comparable to the competitors. In all the competitor vehicles the hood matches the width of the cab. The area around the cooling fans is an extra feature in Volvo which is not present in the competitor's vehicles.

Figure 43: CAT Articulated Haulers (Left), Komatsu Articulated Haulers (Right)

The ground clearance of the competitor vehicles (Figure 43) is comparable with the Articulated Haulers from Volvo.

Motor Graders

Unlike Motor Graders from VCE which follows a more modern design with smooth edges, CAT and Komatsu (Figure 44) have retained a more boxy design. The overall width of the hood is equal to the width of the cab in all the competitor vehicles.

Figure 44: CAT Motor Graders (Left), Komatsu Motor Graders (Right)

Backhoe Loaders

The functional breakdown of the hoods in the Backhoe Loaders of VCE is the same as that of the competitors (Figure 45).

Figure 45: JCB Backhoe Loader (Left), CAT Backhoe Loader (Right)

3.2.4 CONCEPT GENERATION

Based on the different design requirements and dimensional constraints study, there is a possibility to define the architecture for all the product categories in three possible methods

- Architecture based on Engine
- Architecture based on Exhaust pipe
- Architecture based on cooling Inlet/Exhaust

Architecture based on Engine

The size of the engine plays a major role in determining the size of the hood. The position of the engine with respect to the frame is not standardized neither between the product categories nor within a product category. One of the main reason for the absence of standardization is due to the fact that they were designed in different geographical locations.

The relationship between the size of the hood and the engine and the absence of a modular architecture for the engine inhibits any changes to the design of the hood. As any changes to the hood requires a series of changes to the engine and its related components which might result in widespread impact on the design of the surrounding components thereby increasing cost of changes.

Architecture based on Exhaust outlet

The exhaust stack is a common feature found in Wheel Loaders but the position of the exhaust stack differs between vehicles as it is dependent on the exhaust after treatment system. The exhaust after treatment system is directly borrowed from Volvo GTT and the parts cannot be modified. This poses a limitation in reusing parts which is required for defining an efficient modular architecture. As a result, defining an architecture based on the Exhaust after treatment system is difficult as it has a ripple effect on the design of the surrounding parts (See Figure 46).

Figure 46: Architecture based on Exhaust outlet

Architecture based on cooling Inlet/Exhaust

Based on the analysis of the various dimensions and the shape drivers, developing an architecture based on the cooling system shows promising results. The position of the cooling Inlets/Exhausts is common across several product categories. The size of the cooling Inlets/Exhausts has a direct influence on the performance of the vehicle. One of the main advantages of using the cooling inlets as a base for defining modular architecture is that parts can be commonized easily by increasing the size of the inlet/exhaust openings to suit different models (the larger the size of the cooling inlets/exhausts, the better the performance) (see Figure 47).

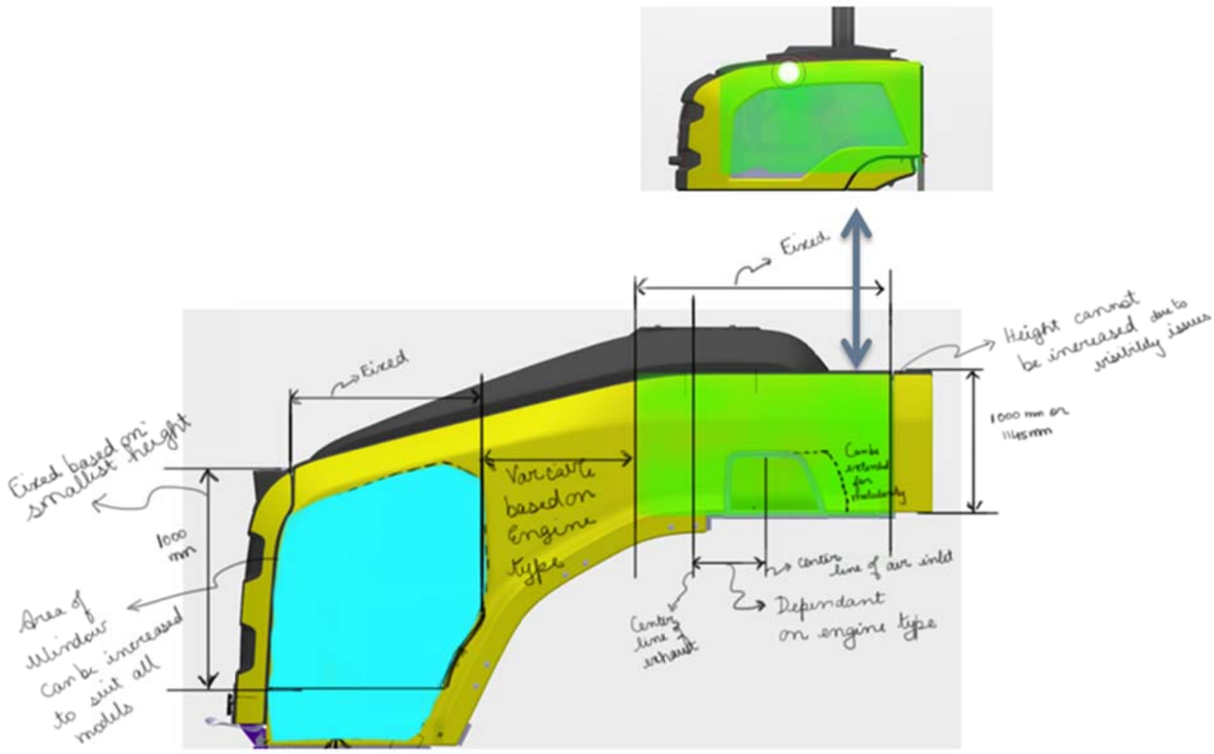


Figure 47: Architecture based on Cooling Inlet/Exhaust

3.3 ARCHITECTURE DEFINITION

The product architecture definition is based on the various evaluated concepts and is defined below. Product architecture is the step in which the functions of a product is allocated to the physical components (Ulrich 1995). The proposal for the product architecture is described below

3.3.1 SIDE PANEL ARCHITECTURE

Based on the concept evaluation, the side panel architecture is described below. The architecture is valid for the side panels of all the Wheel Loader and Motor Graders.

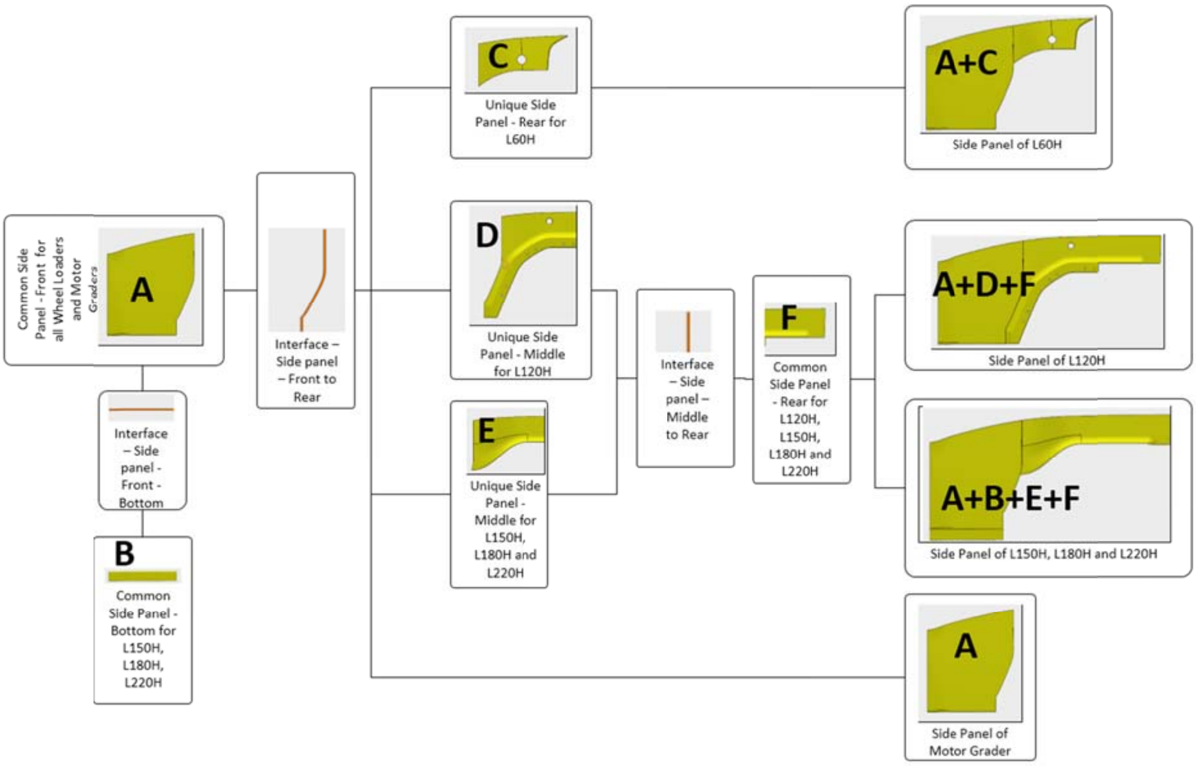


Figure 48: Side Panel Architecture

Based on the performance step study, the front most side panel section (A) highlighted in the Figure 48 can be made common in all the Wheel Loader panels. The region around the engine compartment has one panel for L60 (C) and two panels for all the other models ((D or E) and F). The split up of the architecture can be visualized in Figure 48. An additional extension piece is required for L150 and L220 (B).

The cutout for the air intake is enlarged in order to accommodate the variations in the positions between L120 and L150 hoods.

The main difference between the LH side and the RH side panels is that the cutout for the air intake is present only on the Left hand side of the hood. A blank can be used to cover the opening on the RH side. The difference in position in the cutout for the air intake between L110 and L150 can be matched by having an elongated cutout for the air intake. The dimensions of the side panel is same as that of Motor Grader, as a result the same part can be reused again. The area of the mesh inside the common front module (A) of the Motor Grader is used as a benchmark for the design of the side panel for Wheel Loader.

3.3.2 TOP PANEL ARCHITECTURE

Based on the zone definition, dimensional study and benchmarking both internally and externally, the proposal for the architecture for the hoods of Soil Compactors and Articulated Hauler is shown below.

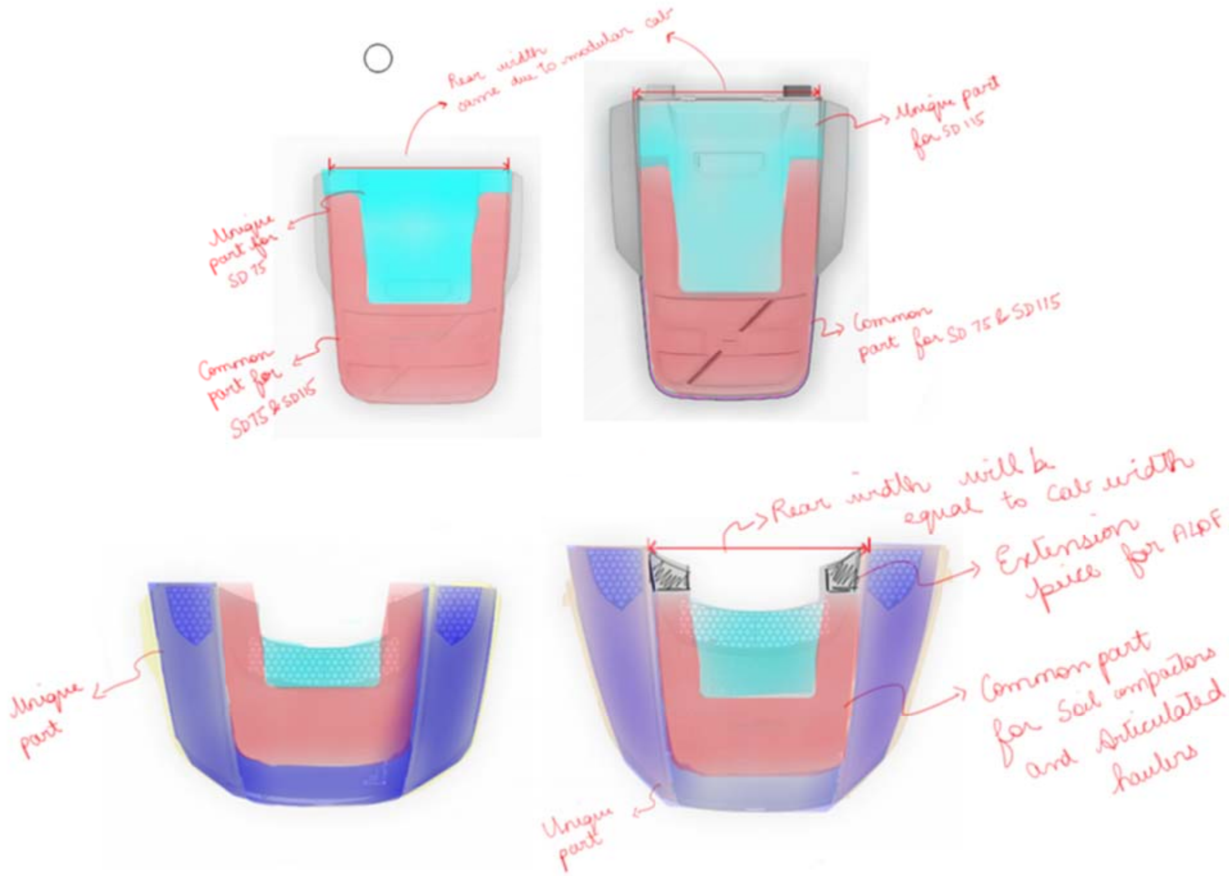


Figure 49: Soil Compactor – Articulated Hauler architecture

Both the Articulated Hauler and the Soil Compactors rear width are equal to the width of the cab. The difference in length of the hoods of the Soil Compactors can be matched by breaking down the entire hood into two pieces. The hood can be broken down in such a way that the same part can be reused in the front section of an Articulated Hauler. The side extension piece around the cooling fans are unique to only the Articulated Haulers, so they can be modified to suit the common front hood (Red panel shown in Figure 49) . The difference in lengths of the Articulated Hauler can be fulfilled by the black panel shown in Figure 49. As a result the red panel can be reused for four different models across product categories. The complete top panel architecture is shown in Figure 50.

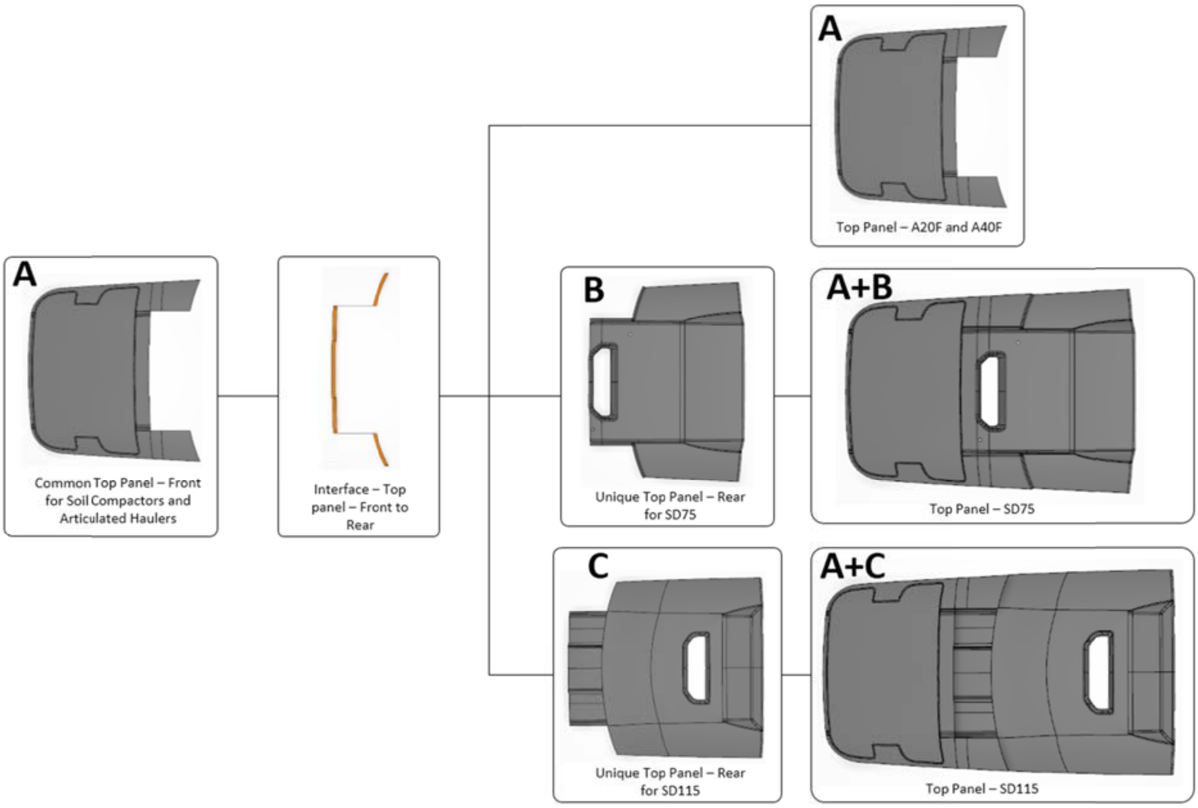


Figure 50: Top Panel Architecture

3.3.3 GRILLE ARCHITECTURE

The driving dimensions of the grille have lots of synergies between them. In order to breakdown the design into a modular chunk an optimization method is used. The optimization method helps to break down the dimensions in such a way that allowable variations can be accommodated within the design, thereby effectively reducing the number of parts. The allowable range within which dimensions can be increased or reduced for the design of the grille is allocated to the gap between the panels during overlapping in the junctions and the bulb seal which is used to seal the hood.

The allowable range for the variation in the dimensions of the hood is kept to 5 mm on all the directions. The summary of the optimization method is shown in Figure 51.

Model	a	b	c	Optimized Mesh width (e)	Gap after optimization (a-e)	Bezel Width (a-e)/2	Optimized Bezel Width	Height of Grille (f)	Grille Bottom Height	Grille Top Height	Top Bezel
L20F	1380	820	440	1000	380	190	200	350	50	40	0
L30G	1420	1020	590	1000	420	210	200	350	150	50	0
L45G	1600	1020	580	1200	400	200	200	350	50	190	0
L60H	1090	860	970	1000	90	45	45	350	250	200	150
L110H	1410	1210	920	1000	410	205	200	350	250	200	150
L150H	1580	1220	1050	1200	380	190	200	350	350	200	150
L220H	1580	1220	1050	1200	380	190	200	350	350	200	150
A20F	1120	1120	680	1000	120	60	NA	350	150	50	150
A40F	1120	1120	720	1000	120	60	NA	350	150	50	150
G930C	1020	700	1000	1000	20	10	10	750	50	200	0
G940C	1020	700	1000	1000	20	10	10	750	50	200	0

Figure 51: Grill Dimension Optimization

Through the optimization method the standard width of the mesh is having two performance steps, 1000mm and 1200mm. The results also yield a common panel height of 350mm which bears the logo (see Figure 52). Two additional panels are used to match the overall height along with the top bezel.

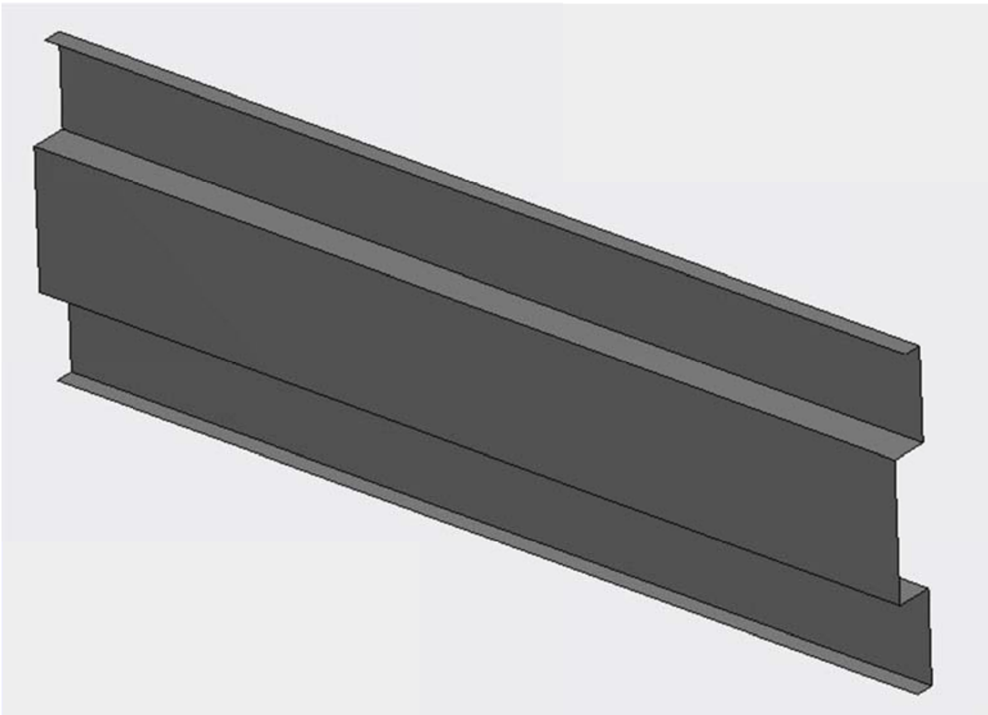
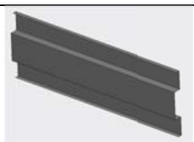
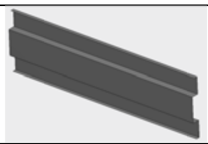
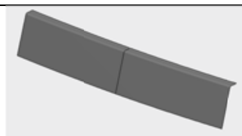
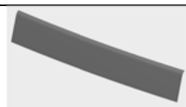
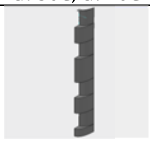
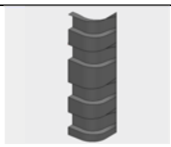
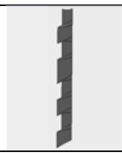
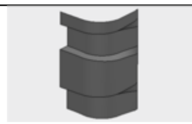
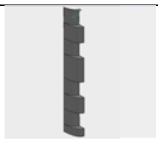
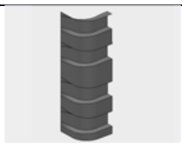
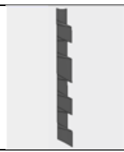
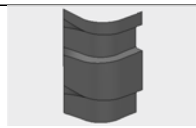
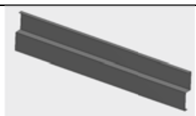
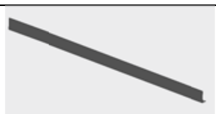
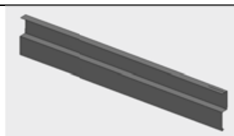
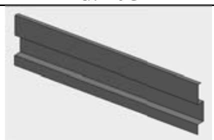
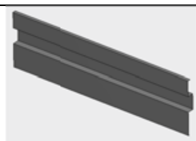
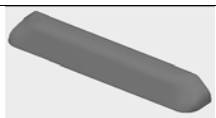
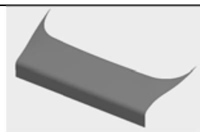
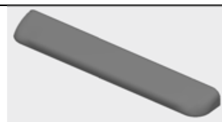


Figure 52: Common Grille Panel (1000mm X 350mm)

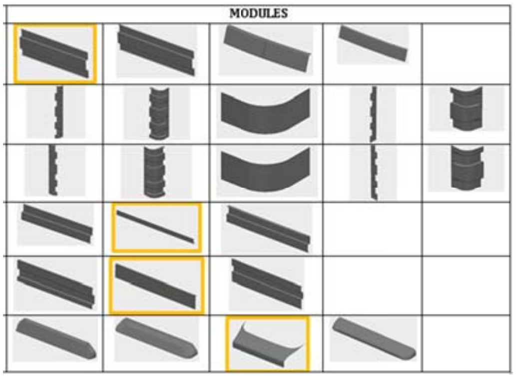
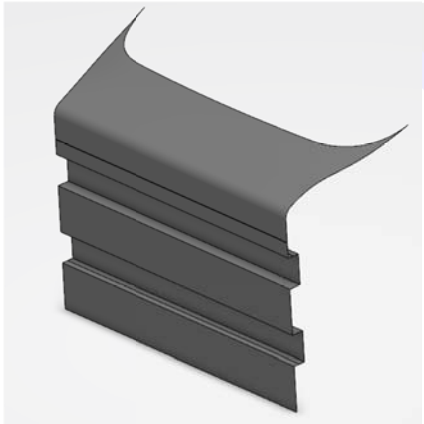
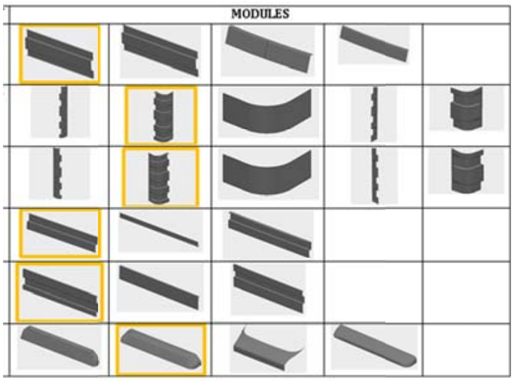
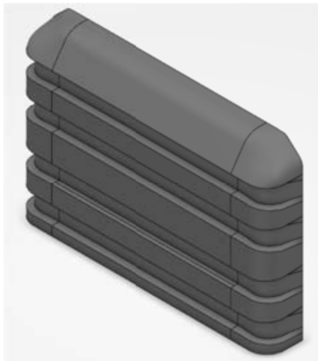
The summary of the modules of the grille architecture is shown in Table 15. As a result of the optimization the number of parts has been reduced from 32 to 26. Even though only 8 parts have been reduced the scope for expanding the range for the future has increased tremendously.

Table 15: Modules - Grille Architecture

CATEGORY	MODULES				
GRILLE CENTER					
	L6OH, L120H, A20F, G930C, G940C	L150H, L220H	SD75	SD115	
GRILLE LH					
	L60H	L120H, L150H, L220H	L150H, L220H	G930C, G940C	L30G
GRILLE RH					
	L60H	L120H, L150H, L220H	L150H, L220H	G930C, G940C	L30G
GRILLE TOP					
	L60H, L120H, G930C, G940C	A20F, A40F, L30G	L150H, L220H		
GRILLE BOTTOM					
	L60H, L120H, G930C, G940C	A20F, A40F, L30G	L150H, L220H		
GRILLE NOSE TOP					
	L60H	L120H	A20F, A40F	L30G	

The number of parts can be reduced further to 20 if the large panels are broken down further into smaller modules of 50mm height and with two widths (1000mm and 1200mm). The extremities of how the different modules can be combined can be seen in Table 16. These modules can be utilized to build up new product variants based on the requirements in the future.

Table 16: Example - Grille Architecture

		A20F 
		L120H 

3.3.4 MODULAR HOOD ARCHITECTURE

Based on the product architecture defined for the top panels, side panels and the grille architecture, the product architecture for the entire hood is summarized in Figure 53 and Figure 54.

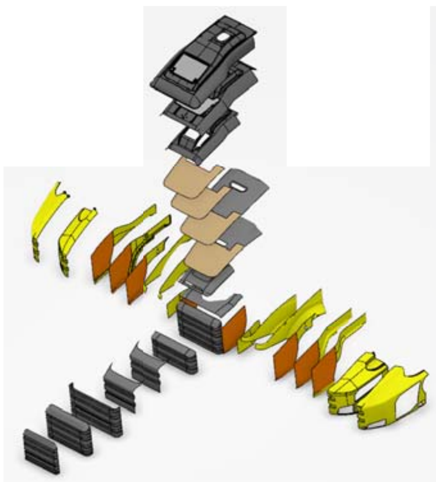


Figure 53: Modules – Hood

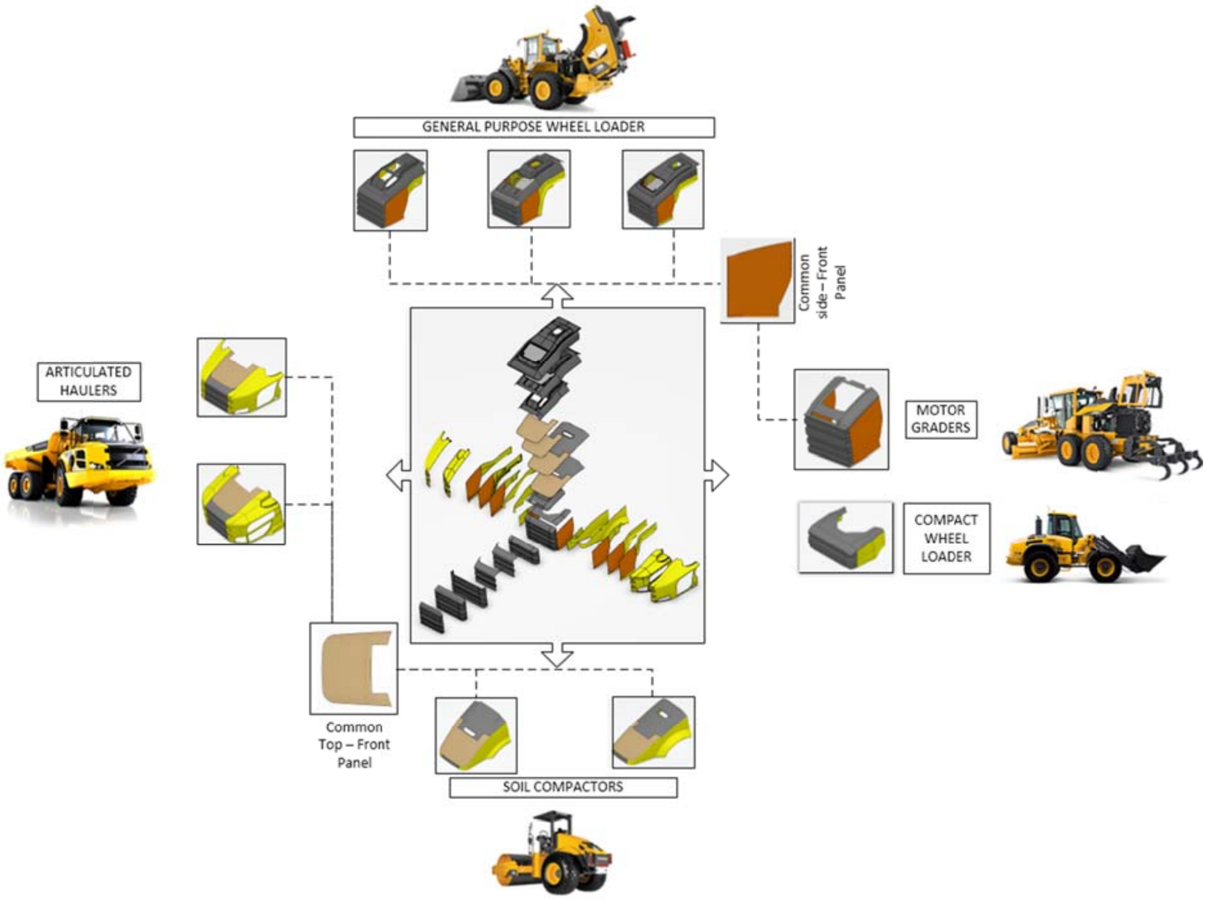


Figure 54: Product Architecture – Modular Hood

4. TECHNICAL DOCUMENTATION

This chapter explains about the features of the software that were used for documenting the technical solution from the study. The flow of the chapter follows a uniform structure where the features of the software is explained first and then examples of how the technical solution is documented with respect to the Modular hood is described. The complete documentation (screen shots) is shown in Appendix III.

4.1 REQUIREMENT MANAGEMENT MODULE

The requirement management module in the 3DX platform is the app used to capture requirements captured through the study. The breakdown of the requirement structure is shown in Figure 55.

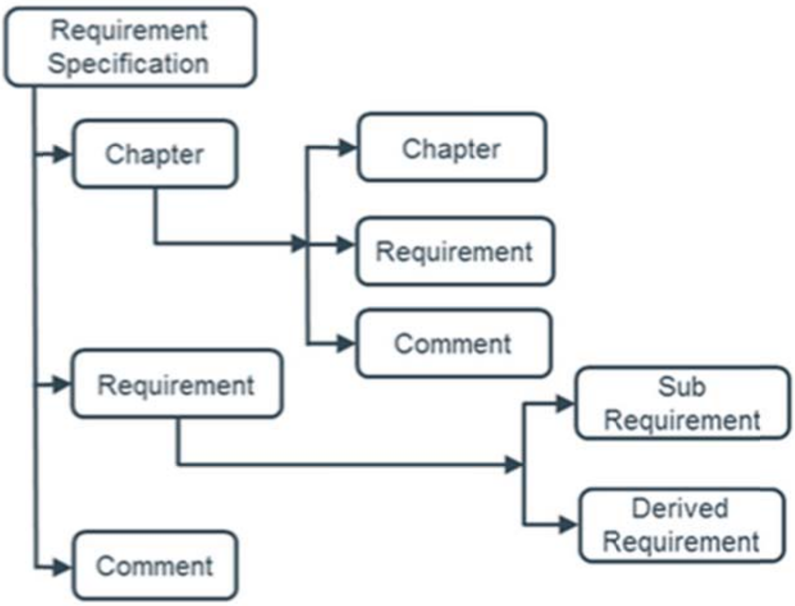


Figure 55: Requirement specification breakdown

Requirement Specification – It is the parent level entity under which all requirements are captured. It can be compared to a book which contains all the requirements

Chapter – Similar requirements are grouped into chapters. It can be compared to chapters in a book.

Requirement – Requirement is the actual requirement captured from the various sources. It can be either a sub requirement (clarification of the requirement) or a derived requirement (derived from the requirement with a small variation).

Comments – Comments are used to emphasize additional details on the requirement

4.1.1 FEATURES OF THE REQUIREMENT MANAGEMENT MODULE

Some of the salient features of the requirement management module are described below

Roles

Access to the different parts of the module can be restricted based on different user roles. For example, the Requirement manager for a project X can view and edit the requirements for project X only and not project Y.

Access to Microsoft office suite

There is a seamless integration between the 3DX platform and Microsoft office suite. Requirements captured previously in word documents and excel sheets can be directly imported into the Requirement management app along with the pictures (Rich text format is compatible with 3DX platform) which reduces the effort required to capture already available information and also add more visual detail to the requirements captured. The requirements tab in Microsoft word is shown in Figure 56.

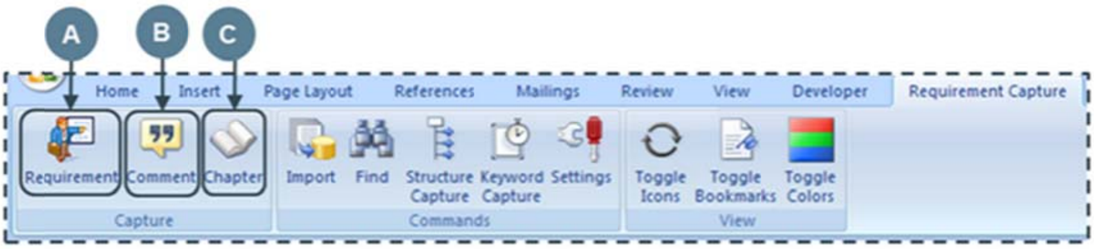


Figure 56: Requirement Capture tab in Microsoft Word

Version Management and Traceability

Changes in the requirements can be captured as revisions, as a result the evolution of the requirements can be visualized easily using the requirement management module.

The ability to allocate the requirements to various entities like configuration features, configuration options, physical models etc. enables the ease of traceability. Entities which are affected by the change in requirement can be visualized without much hassle resulting in reduced lead times for product modifications.

4.1.2 EXAMPLE OF REQUIREMENT MANAGEMENT - MODULAR HOOD DESIGN

A part of the total requirements captured can be seen in the Figure 57. A general breakdown showing requirements specification, chapters, sub chapters, Requirements and derived requirements is shown in Figure 57.

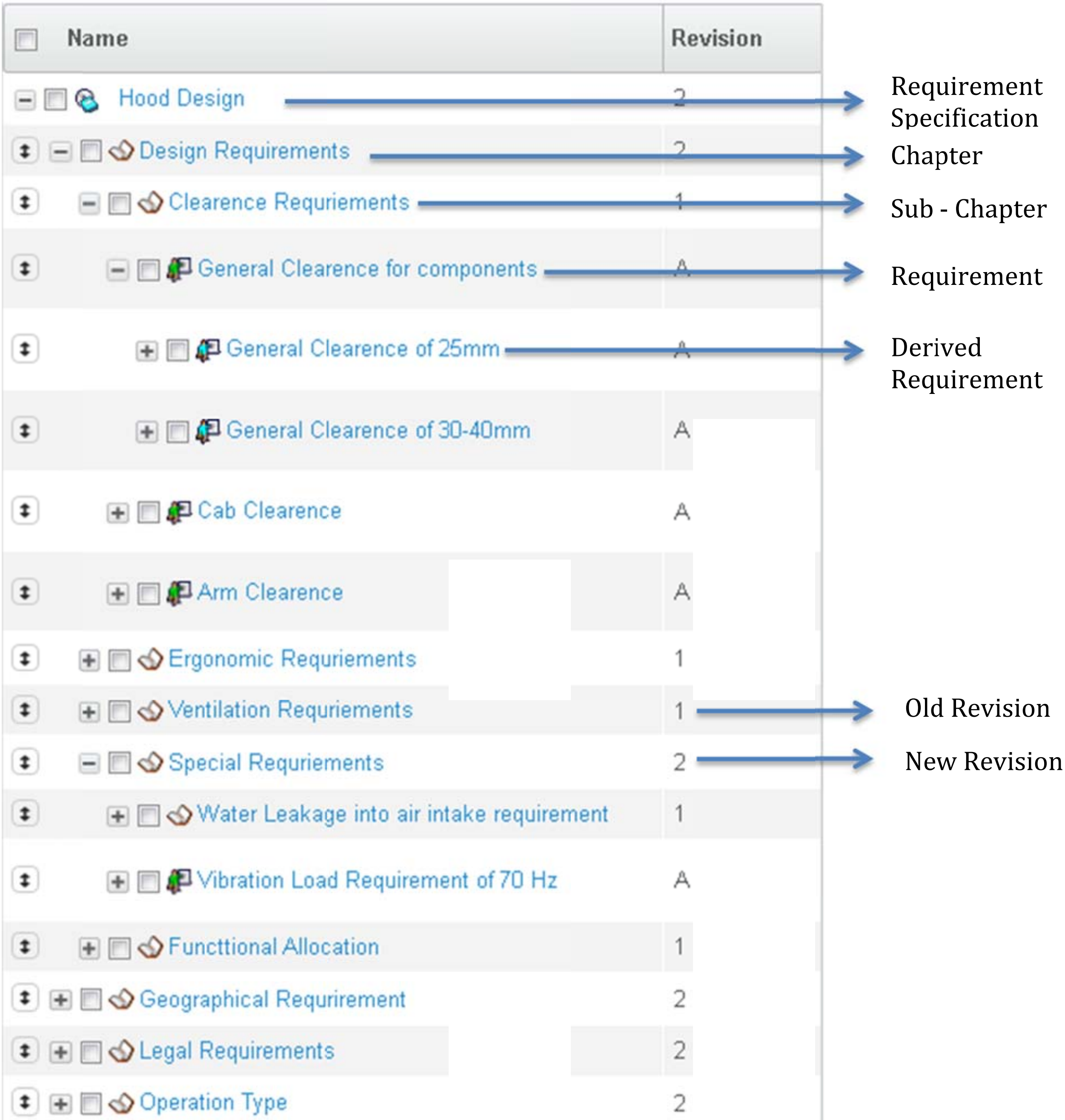


Figure 57: Requirement Management – Modular Hood

The complete list of requirements and the configuration features and options are summarized in Appendix III.

4.2 VARIANT MANAGEMENT MODULE

The variant management module is used to define the configuration features, configuration option, configuration rules, define product configurations etc. The description of the different segments is explained below.

4.2.1 DEFINITION OF CONFIGURATION FEATURES AND CONFIGURATION OPTIONS

The Configuration features and options are handled in the Variant Management module app in the 3DX platform.

The Variant management app consists of three axes of variance (shown in Figure 58)

- Product hierarchy that organizes the product in vertical direction
- Product Revision that manages the product evolution along time
- Product variability that manages the variation of the product based on marketing or technical choices

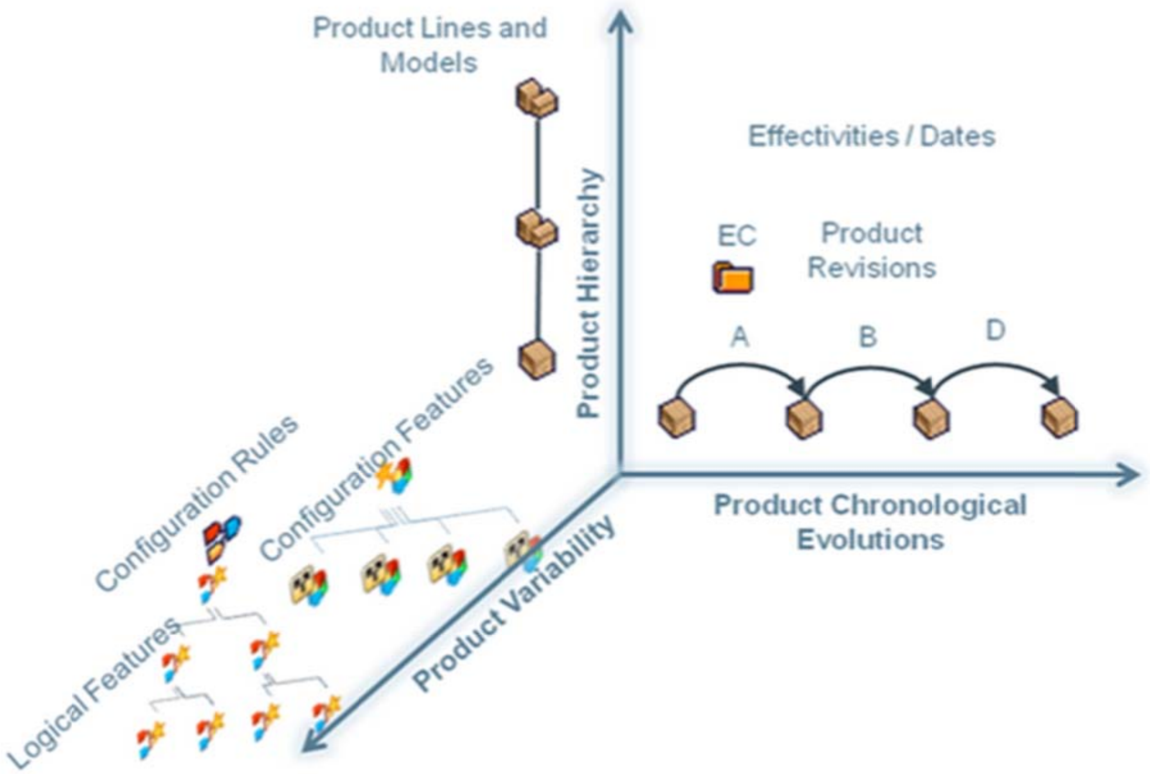


Figure 58: Variant Management axis

4.2.2 CONFIGURATION FEATURES AND OPTIONS

Configuration features and configuration rules are on the product variability axis. Configuration features are the marketing/technical features which will be used to configure the product and configuration option is the individual option which will be selected to create a unique product (see Figure 59).

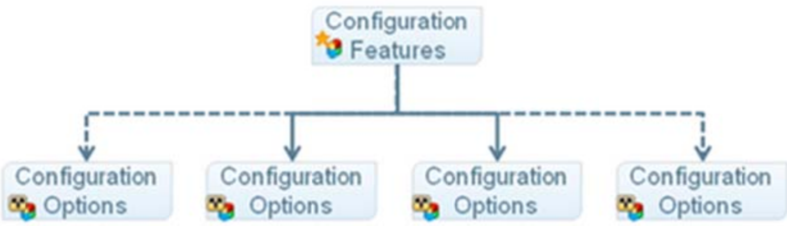


Figure 59: Hierarchy - Configuration features and options

4.2.3 FEATURES OF THE VARIANT MANAGEMENT MODULE

Some of the salient features of the Variant management module are described below

Roles

Access to the different parts of the module can be restricted based on different user roles. For example, access can be given to the product engineer to create new products based on predefined rules but no access is given to create a new configuration by breaking the rules. Product manager can be given access to break the rules and create new product configurations.

Version Management and Traceability

Changes in the features and options can be captured as revisions, as a result the evolution of the configuration features and options can be visualized easily using the Variant management module.

The ability to allocate the requirements to various entities like configuration features, configuration options, physical models etc. enables the ease of traceability. Requirements and products which are related to the various configuration features and options can be easily traced.

Effectivity

Date effectivities can be allocated to various features and options. For example, if a specific requirement arises for vibration, say "Vibration Requirement for 70 HZ is valid from January 1st 2015" on Soil Compactors, Configuration features and options related to the new vibration requirement are assigned date effectivities which result in the options not being visible on Dec 31st 2014 but visible on the Jan 1st 2015.

4.2.4 EXAMPLE OF CONFIGURATION FEATURES AND OPTIONS - MODULAR HOOD DESIGN

An example of the configuration features and options for the modular hood is shown in Figure 60. The column display name shows the list of configuration features and options. The column singular/multiple states that whether the options selection can be singular (only one option can be selected) or multiple (many options can be selected). The entire features can be sequenced which controls the order of options when selecting the product configuration. The date effectivities control the timeline within which the options are valid. This results in a set of options been shown on one day and a completely new set of options another day. The complete list of Configuration features and options are listed in the Appendix III.

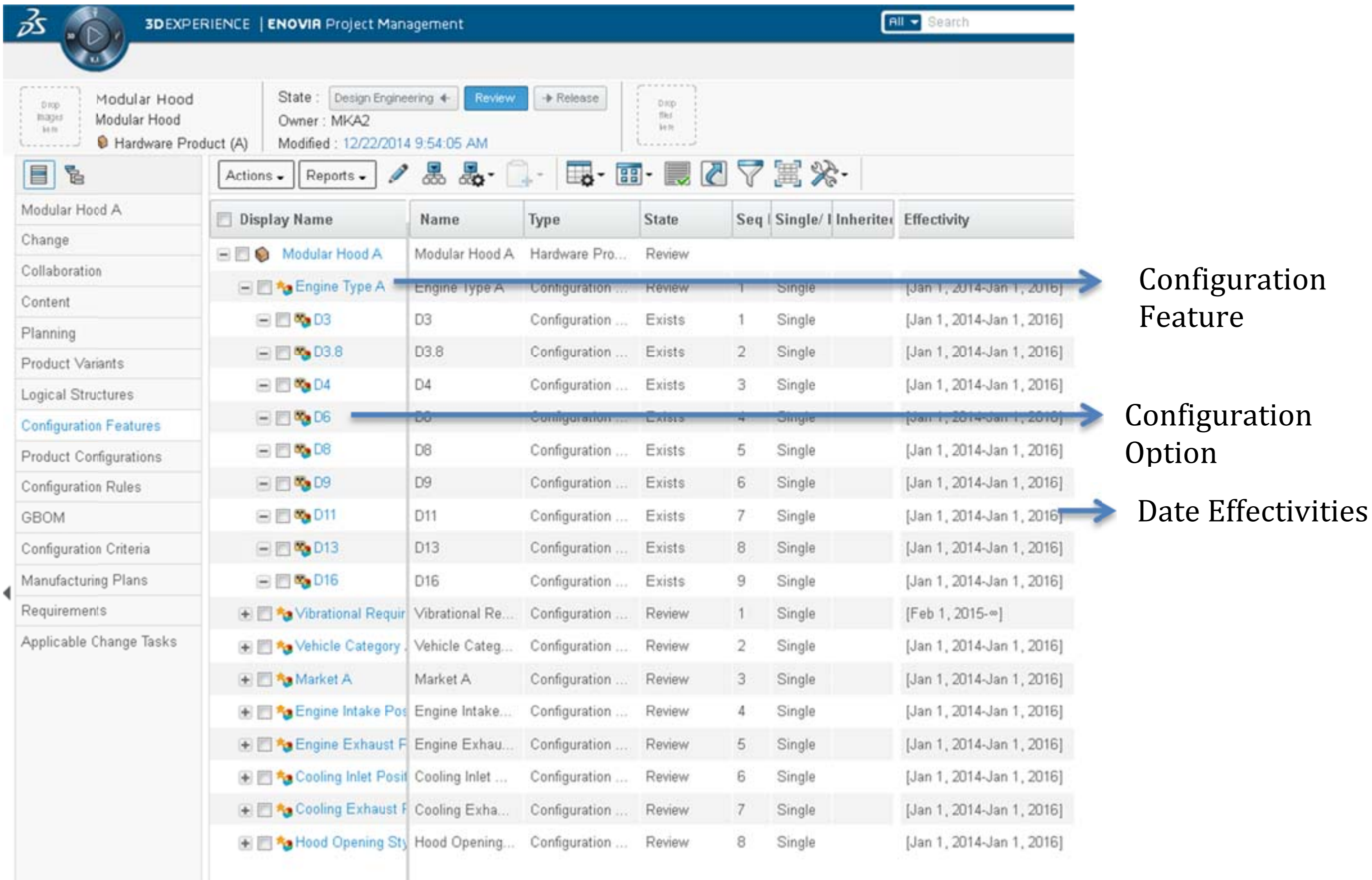


Figure 60: Example Configuration features and options

4.2.5 DEFINITION OF CONFIGURATION RULES

Configuration rules guide the selection of the configuration options while creating a product configuration. Simple boolean rules are used to describe easy or very complicated rules, thereby controlling how different options can be combined.

Comparison Operator

Three different comparison operators are used for creating the configuration rules

Incompatible – Defines that the two features cannot be included together

Co – Dependent – Defines that the two features must be included together

Requires – Defines that feature/option D must be included whenever option B is included but B doesn't have to be included when feature/option D is included. In this case, B requires D (see Figure 61)

Figure 61: Comparison Operators

When creating a configuration rule, apart from the comparison operators, boolean operators (AND, OR and NOT) can also be used within the expressions to combine different configuration options so that multiple options can be combined for creating the rules which are compact in nature (See Figure 62). An error message is used to explain why certain combinations are allowed and not allowed.

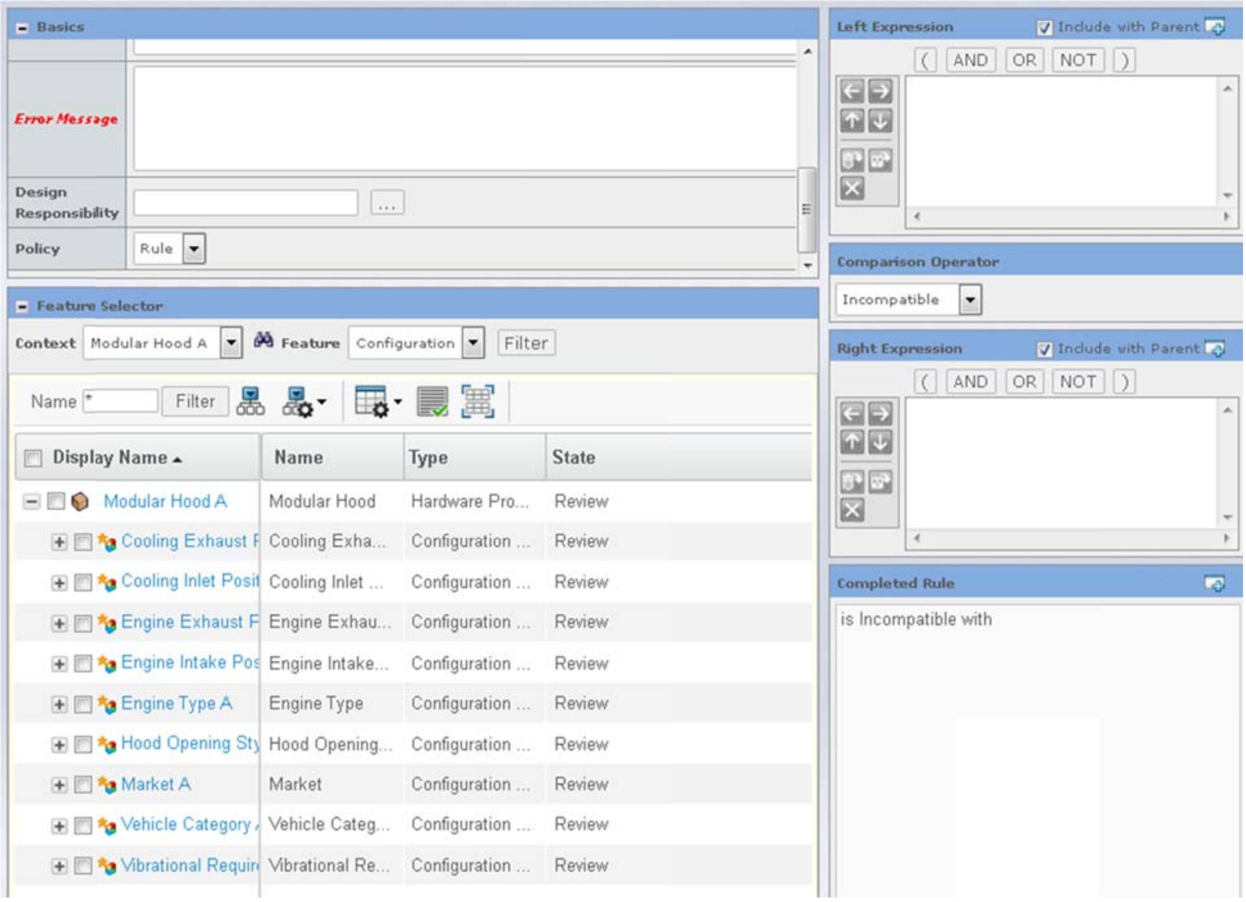


Figure 62: Configuration rule definition window

MARKET PREFERENCES

Marketing preferences is used to limit the configuration options to a selected few based on the selected configuration option. For example selecting the vehicle category as compactors limits the engine options to D3.8, D4 and D6.

4.2.6 EXAMPLE OF CONFIGURATION RULES AND MARKETING PREFERENCES

One example for configuration rules and marketing preference is shown in Figure 63. Figure 63 shows the configuration rule for Wheel Loader. It shows that the engine intake on side panel requires the exhaust on top for a Wheel Loader as it has an exhaust after treatment system on top of the engine.

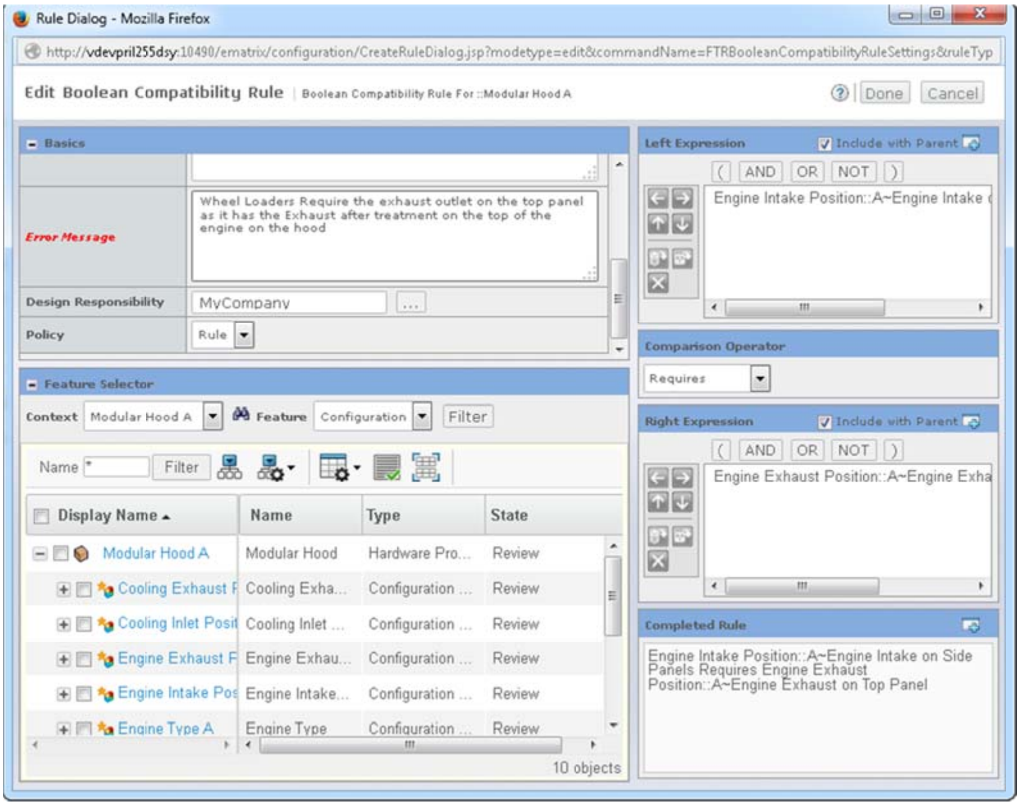


Figure 63: Configuration rule definition - Wheel Loader compatibility

Figure 64 shows an example for the marketing preference where selecting vehicle category as Hauler limits the engine selection option to D11, D13 and D16.

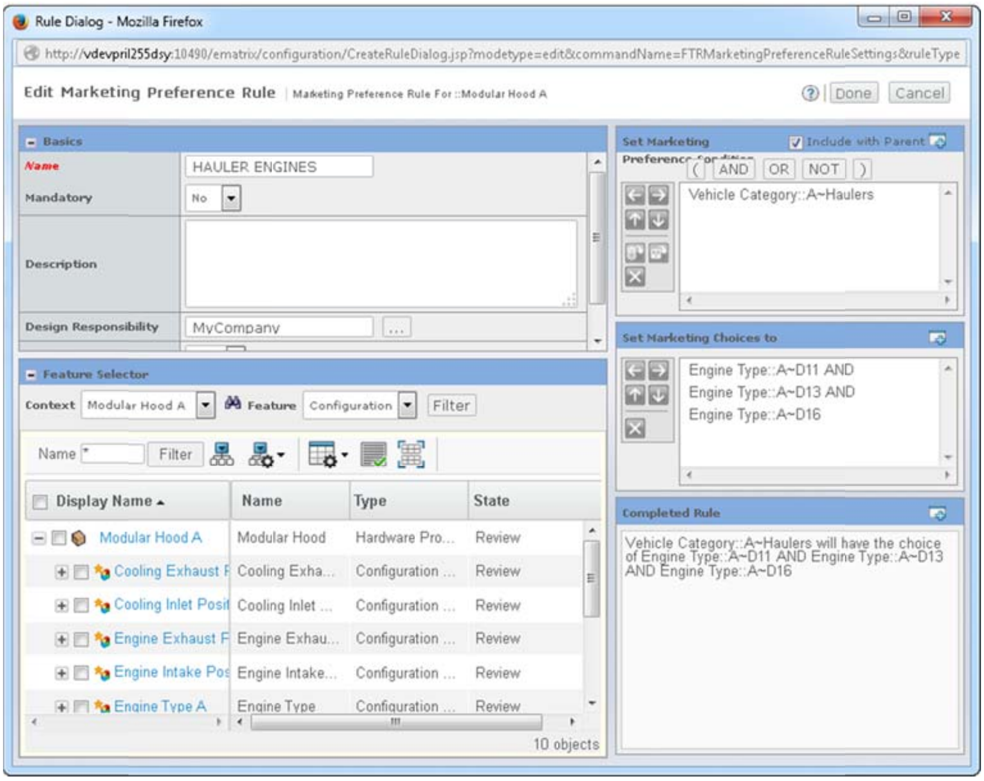


Figure 64: Marketing preference definition – Hauler engine compatibility

The summary of all the configuration rules and marketing preferences are attached in Appendix III.

4.3 CAD INTERFACE

Based on the complete study of the product categories and the concept architecture, a product assembly is created with the functionally broken down modules (See Figure 65). CAD models of all the variants are added within their respective modules. Then the parts are positioned in their respective design positions.

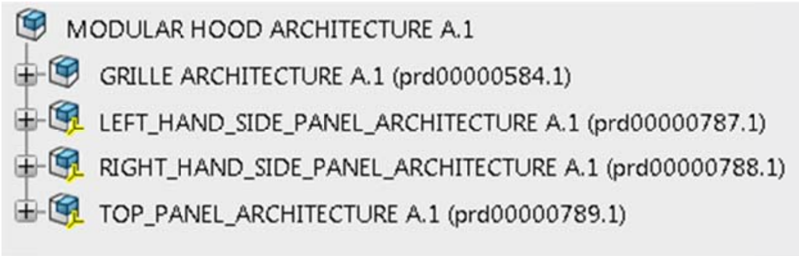


Figure 65: Product tree definition

4.3.1 DEFINTION OF EFFECTIVITIES

Effectivities are applied to the cad models after the creation of the modules. Effectivities in this context refer to linking the configuration features and options to the related CAD model. Applying the effectivities follows the below mentioned steps.

Step 1: Linking the product defined in web interface to the physical product defined in the CAD environment. This is done by adding the corresponding product in the configuration tab inside properties of the parent product. Enable Configuration criteria, date and product states in order to apply the effectivities. An example of the assignment of the configurations to the top panel architecture is shown in Figure 66.

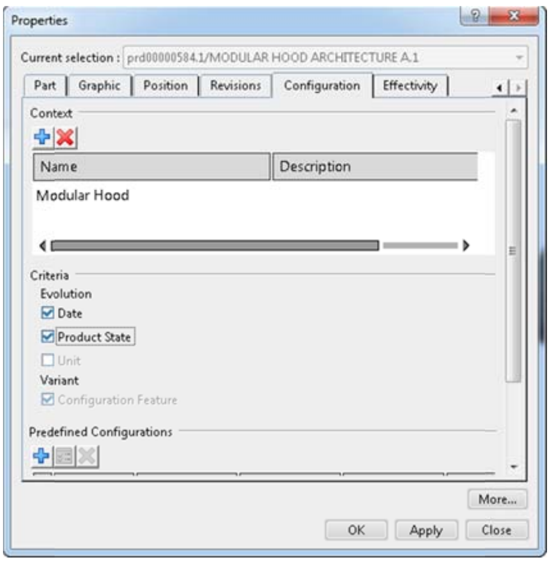


Figure 66: Assignment of the configurations to the Models

Step 2: Edit the effectivities of the individual modules by adding the configuration features or options to their respective physical counterparts.

The effectivities can be defined in an intelligent manner using the software where multiple options can be assigned to the same part (Figure 67) thereby aiding the definition of parts which are common for several options thereby aiding the definition of the modules.

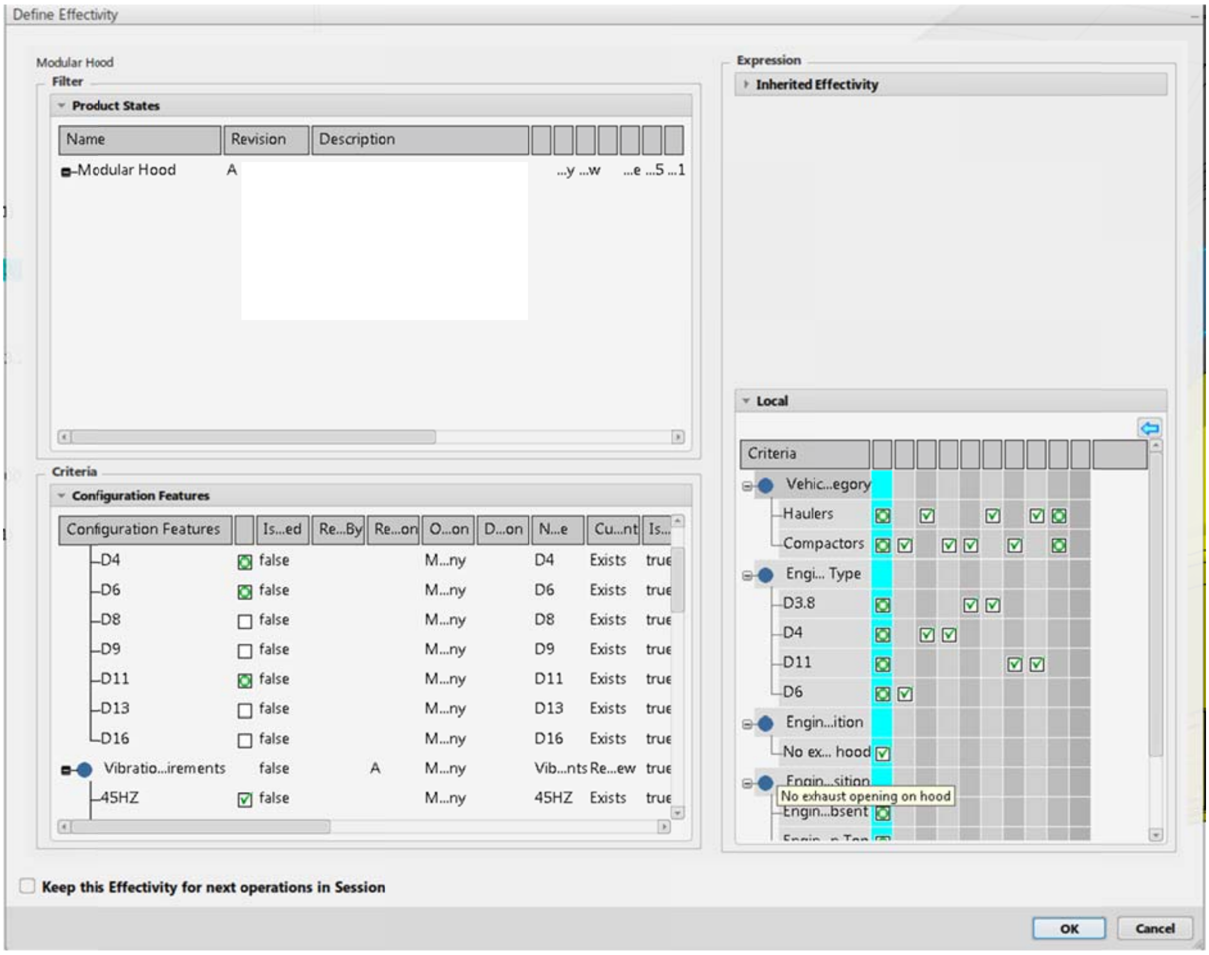


Figure 67: Assignment of Effectivities

4.3.2 PRODUCT CONFIGURATION

Based on the configuration features, configuration options, configuration rules and marketing preferences, product configurations are created to filter out the 150% product structure (A product structure which contains all the options and variants) and move on towards creating EBOM and other related tasks. The product configurations act as glasses aiding to filter the product structure into a specific instance. In order to view a product structure from a different perspective the glasses (filter) needs to be changed.

Date effectivities can be applied to the product configurations to filter out the valid options. Unlike configuration features or configuration options, Product configurations can be created both in the web interface and the cad interface.

Since the Configuration features and options are connected to the CAD models, once the options are selected, their respective CAD models are filtered. Figure 68 shows the example of the product configuration window where configurations can be built up (bottom up approach) or refined (top down approach). Symbols indicate whether options are selected manually or automatically based on rules as shown in Figure 68. As the options are selected the product configuration is built in real time on the right hand side window. Product configurations can be created by different users either by following the defined technical rules or breaking the rules based on the roles provided to different users.

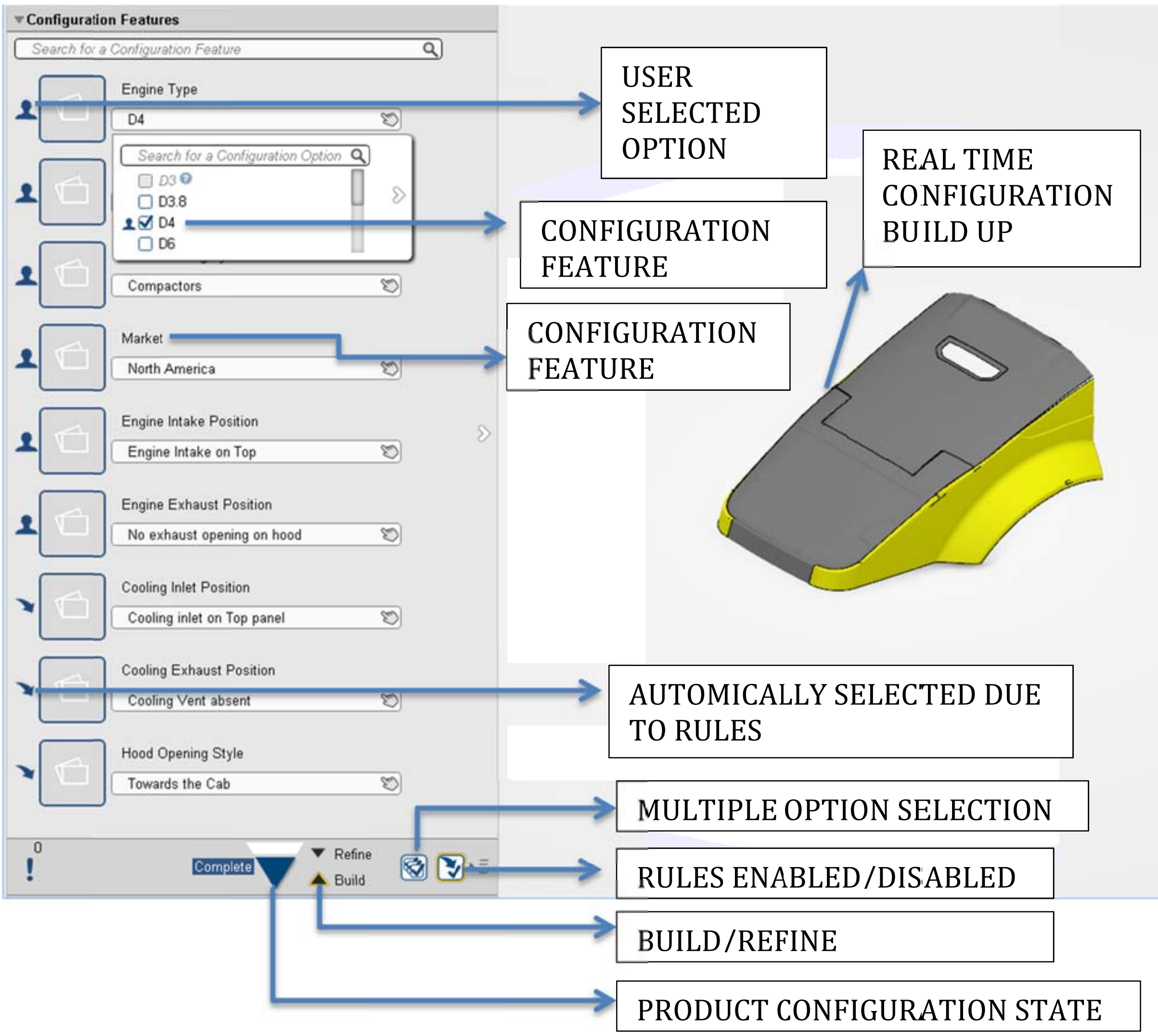


Figure 68: Product Configuration creation window

5. MANUFACTURING METHODS

This chapter explains about the challenges in modular design of products, design for assembly and possible methods for assembly of the modular components which helps to realize the modular design of the hood.

5.1 MODULAR DESIGN - CHALLENGES IN MANUFACTURING

Modular solutions may sometimes require additional assembly operations to realize the design. This poses challenges with respect to logistics, inventory, manufacturing methods, etc. The gaps and flush requirements on the mating parts may pose challenges on how the modular solution is manufactured.

Apart from the above challenges, questions on whether the part should be assembled at the suppliers end or inside the plant in sub assembly lines needs to be researched in order to take a decision on where to assemble the product. In the quest to improve better reusability of panels, individual panels may be broken down resulting in increased number of split lines. The ability to provide a modular solution which also appeals aesthetically is a challenge due to the increase in the number of split lines.

Advantages of breaking down the components can be smaller tools and thereby reducing the overall cost of the components. Another advantage of having the modules manufactured by the supplier is higher speed of production and reduced costs (Wits & Vaneker 2011).

Supply chain too has a role to play in the modular design of components. The relationship between the OEM and the supplier plays an important role in the design of components (Ülkü & Schmidt 2011). Modular design requires less investment in tooling and infrastructure compared to integral design.

5.2 DESIGN FOR ASSEMBLY

Design for assembly is a method where the aspects of assembly are considered from the early stages of design. Studies reveal that enormous benefits such as lower assembly and manufacturing costs, improved quality, reduced time to market, etc. can be achieved through this method. (Boothroyd & Alting 1992). Challenges posed by the assembly process are identified in the start of the design stage itself through interviews with experts, benchmarking etc. Some of the proposals to solve this problem are described below.

5.2.1 DESIGN OF INTERFACES

Based on the proposed modular architecture, the hood is divided into multiple parts. In order to satisfy the design requirements with respect to gap and flush, the design of the interface plays a vital role. The interface between the components can be done in the following methods

INTERFACE OF PANELS

The panels in the hood can be aligned by the following methods

Simple Overlap

A simple overlap is a mating procedure shown in Figure 69. Variations in the range of .01 mm can be accommodated easily. This method is a simple assembly method between two panels but has a drawback on the exposed fastener which might have a negative effect on aesthetics.

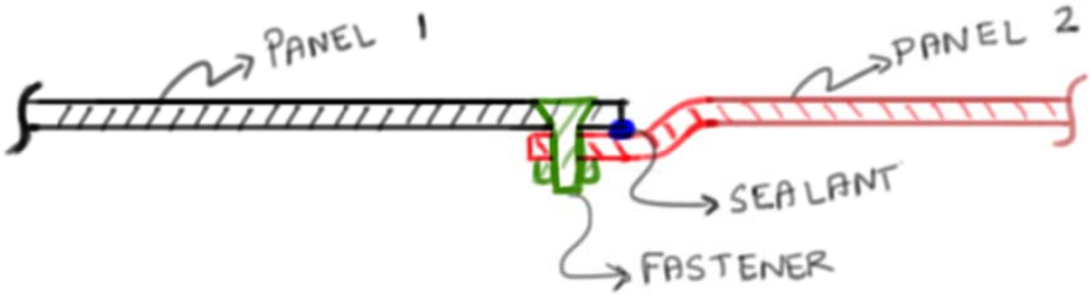


Figure 69: Simple Overlap

Folded Overlap

A Folded overlap is shown in Figure 70. The disadvantage of exposed fasteners can be avoided using a folded overlap. The tolerances of the interfaces need to be kept tight in order to facilitate ease of exchange of parts.

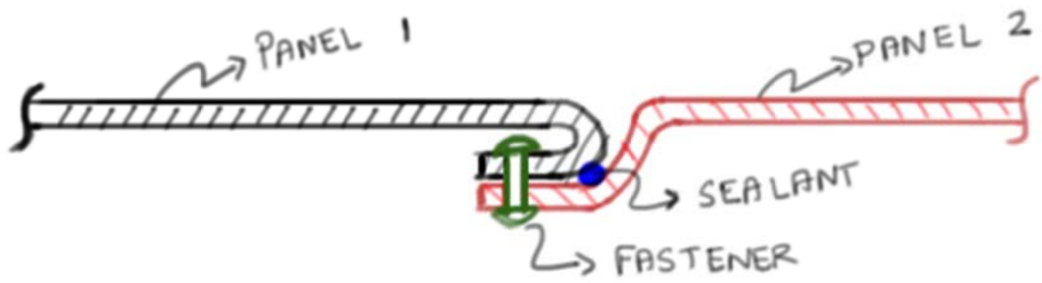


Figure 70: Folded Overlap

Interface brackets

Simple brackets can be used to join two panels as shown in Figure 71. Even though an additional part is needed to assemble the panels the complexity in the manufacturing with respect to the tooling might be reduced using this method.

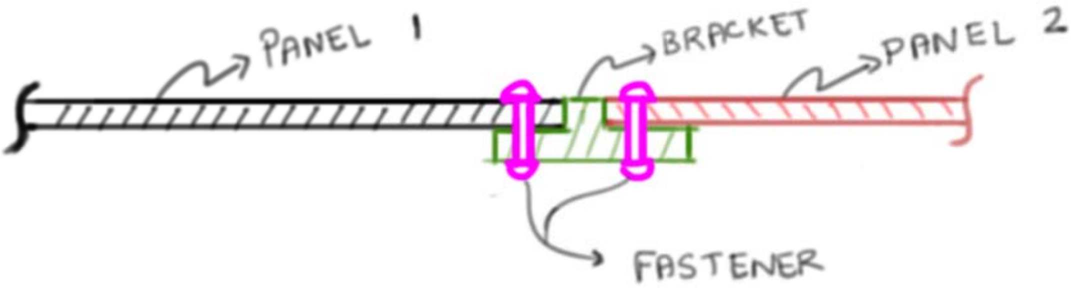


Figure 71: Interface Brackets

FASTENING METHODS

Once the panels are aligned, they have to be fastened with each other and then to the superstructure. Fastening can be either temporary or permanent fastening. The advantages and disadvantages of temporary and permanent fastening are summarized in Table 17.

Table 17: Fastening of Panels

Type	Examples	Advantages	Disadvantages
Temporary Fasteners	Rivet, Screw, Clips	• Easy replacement of parts during accidents • Logistics is cheaper as part size is smaller if assembled inside the Volvo factory • Use of standard parts, resulting in use of standard tools	• Increase in tact time • Additional fixtures required for assembly if multiple interfaces are used
Permanent Fasteners	Ultrasonic plastic welding,	• No impact on the tact time • No problems in gap and flush	• Negative effects on logistics due to larger size • Replacement of complete panel required in case of damage

5.2.2 DESIGN OF GRILLE

The proposal for the assembly of the grille is described below. Individual meshes in the grille can be assembled using the proposed method and can be further strengthened using the superstructure.

Proposal for attachment

The individual meshes in the grille needs to be stacked upon one another in order to cater the different dimensional requirements. One simple pattern would be using alternative male and female ends. The disadvantages of using an alternating male and female ends can be seen in Figure 72. Three different patterns are compared for evaluating the best option (See Figure 73).

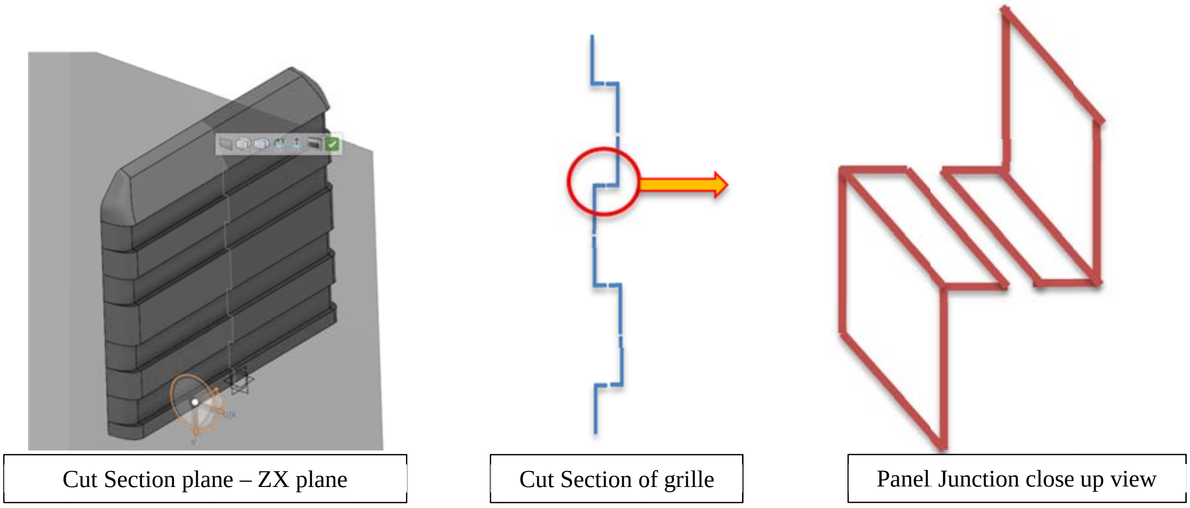


Figure 72: Section Plane – Grille

Pattern 1 – Pattern 1 has male ends on one mesh panel and female ends on the other mesh panel. The same patterns can be rotated and stacked up for building up the different variants. The disadvantage of this pattern is that two unique mesh panels (red and blue) are required to achieve an interlock between the mesh panels. This results in an increase in the number of part numbers.

Pattern 2 – Pattern 2 has alternate both male and female end on one mesh panel. The problem with this type of arrangement is when the mesh panel is rotated it might result in two male ends clashing with each other and this arrangement too results in unique mesh panels.

Pattern 3 – Pattern 3 is inspired by Lego clips (Figure 73). The mesh panels have female ends in all the edges and separate male connectors are used to join them. The advantage of this pattern over the others is that even though the number of parts is two, the larger part is unique and the smaller universal attachment can be made as a standard interface between the two parts.

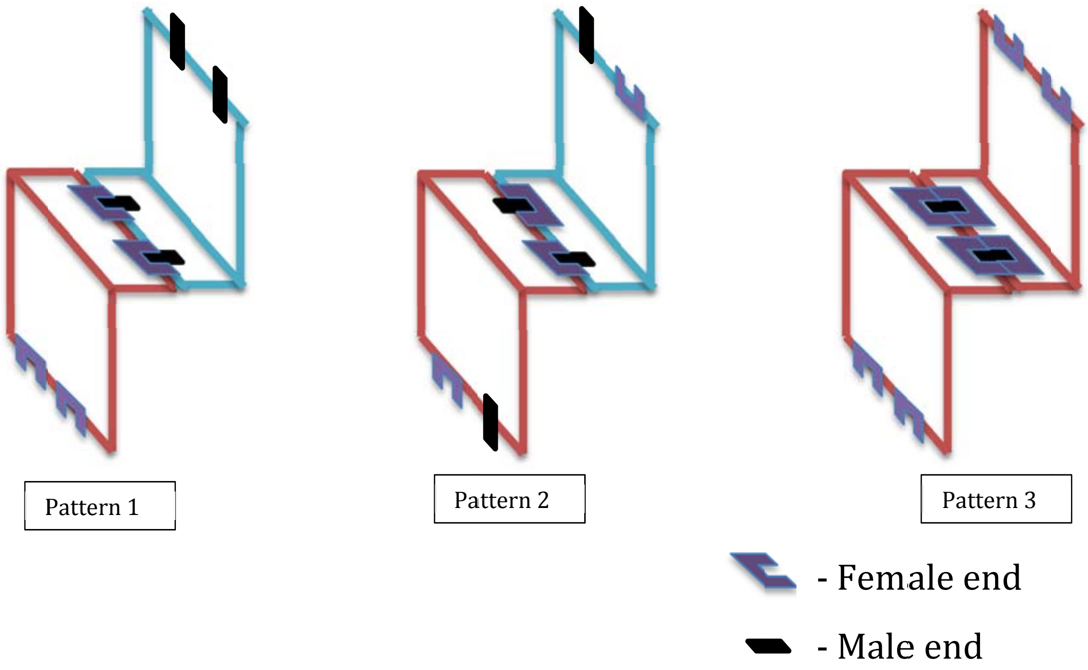


Figure 73: Grille Architecture – Pattern Evaluation

5.3 COST ANALYSIS

This section explains about the cost analysis of the proposed modular technical solution for the hood. Based on the internal sources, the reduction of part numbers due to the modular architecture proposal can have potential savings of approximately 1 Million SEK. The saving will be more as the modular design solution is implemented in steps. According to sources inside VCE when a new product is introduced only 20% of the parts are reused and the remaining 80% is unique. If modular product architecture is introduced the cost of introducing the modular architecture may be high for the first product but as new products are released more and more parts can be reused. This is an advantage of using a modular design solution. Cost analysis is kept to a minimum as data required to estimate the cost of the tooling were not available during the time of study.

6. DISCUSSION

This chapter provides a reflection and critical thinking of the different sections in the report.

6.1 DISCUSSION ON NEEDS MAPPING

Capturing the requirements from two different perspectives helped to cover the requirements of the hood in a holistic manner. Distinguishing the requirement capture methods into the generic method helped to analyze the problem and decompose the hood with respect to the design requirements, whereas the functional perspective helped to identify the relationship between the features of the hood and its impact on design which was effectively used in the configuration feature and option definition in the 3DX platform.

One of the main driving factors for breaking down the hood into five different segments was the need to satisfy different stakeholders' needs with a common solution. The interface analysis helped to understand the underlying relationship between the parts of the hoods and its surrounding components but it was not implemented in the documentation of the technical solution as the interrelationship between the different surrounding components and the hood design needed to be defined. Due to the explorative nature of the study, this was not considered in the technical documentation.

6.2 DISCUSSION ON THE CONCEPT DEVELOPMENT

The concept development study followed a systematic breakdown of the hood based on its functions for different product categories and also comparing them based on their shapes and dimensional constraints. Volvo's internal method used for modular product development along with the generic product development methodology helped in approaching the problem in a structured manner. The Modular cab was an excellent example of how a product is broken down based on its functions. Lots of synergies were found within and between product categories. The study was limited consciously to the top level assembly due to its explorative nature.

Constraints with respect to the exterior dimensions were strictly adhered to, so that there is no violation of visibility regulations. The constraints put forth by the existing components are retained so that the proposed technical solution can be easily realized without affecting the design of the surrounding components. The study even though is elaborate on the top level is not complete without studying the effects on the surrounding components too. More research needs to be carried out in this area.

The method of optimization used to find the least number of common parts helped to reduce the number of parts required to satisfy the requirements of different models. Research needs to be carried out to find out if any mathematical method is available to reduce the numbers further.

Tradeoff's made between the USP's and the design constraints play an important role in implementing a modular solution. Defining the architecture of the engine bay and its relationship with respect to the cab and axle plays an important role in defining the design boundaries of the hood in all the product categories.

The method used for visualizing the dimensions using bar charts was simple and very effective to identify the synergies in design. The impact of trading off the USP of visibility requirements in Soil Compactors with respect to the modular design needs to be studied. From the preliminary studies, the scope of changing the visibility requirements from 1mX1m to 1mX1.5m helps in panel's reusability on the two sides. It also helps to organize the engine bay thereby commonizing the alignment of the radiator and the cooling system.

6.3 DISCUSSION ON THE TECHNICAL DOCUMENTATION

Various features of the 3DX platform were effectively used to document the technical solutions. The implementation of the configuration features, configuration options and the rules were simple straightforward tasks. The training provided on the different modules along with the online help (Documentation) strengthened the understanding of the software and eased the use of the software. The 3D configurator which shows a real-time light weight model made the product configuration creation process more intuitive. The seamless integration between the web and CAD interface reduced the time taken to configure the products, i.e. when a new configuration option is created in the web interface it is immediately visible in the CAD interface.

The open nature of the software posed a different challenge due to the wide scope available to document the solutions (Documentation can be done with multiple methods). The methods chosen for documentation were mainly oriented towards the interests of the product managers and designers. The documentation of the technical solutions does not capture any manufacturing related documentations which can be carried out in the future.

The ability of the software to collaborate with different people at the same time improves the overall efficiency of the product development process. Research suggests that supply chain collaboration has enabled companies to compete more efficiently in the market by improving design quality, enabling reuse, lowering product costs, etc. (Banker et al. 2006)

6.4 DISCUSSION ON THE MANUFACTURING METHODS

Manufacturing assembly process feasibility study plays an important role in realizing the proposed technical solutions. One of the main indicators of the success of a concept lies in the ease with which it can be commercialized. The design for assembly concepts provides a strong base in providing an effective and efficient solution for the interfaces. The proposed assembly methods describe the design of the interfaces of the panels and the grille in a simple and effective manner.

The advantages and disadvantages of having a modular solution are described in the manufacturing section clearly highlighting effects on logistics, inventory, manufacturing method etc. The proposal for the manufacturing method is rudimentary on a concept level which needs to be further studied upon. The attachment method proposed for the grille follows a unique “Lego block like” design which effectively reduces the number of components. Cost analysis of the tooling needs to be carried out in order to justify the business case of the modular hood proposal.

In order succeed in a modular architecture, the whole portfolio needs to be developed in parallel until the end of the concept phase to secure full benefit of it. Final design can be done later and introduced in sequence maintaining the interfaces defined.

7. CONCLUSIONS AND RECOMMENDATIONS

This chapter describes the important findings of the study and also the recommendations for the future.

7.1 IMPORTANT FINDINGS

This project followed the footsteps of the modular cab design. The overall output of the study resulted in the proposal of a common product architecture covering four different product categories for the design of the hood. A modular architecture for the grille is also proposed. Possible assembly methods for the interfaces of the individual panels and grille meshes in the hood have also been proposed which needs additional research on economic viability.

The method of optimization used to achieve the least number of part numbers in the design of the grille meshes was very effective in reducing the number of part numbers from 32 to 26. The number of part numbers can be reduced further to 20 by breaking down the meshes into smaller parts but the effect on manufacturing needs to be studied before a decision is made. The entire design proposal is based on the fact that few changes are made to the existing systems. From the study, the benefits of having modular product architecture far outweigh the existing integral design solution.

The 3DX platform plays an important role in documenting the technical solutions effectively. The seamless integration between the web and CAD interface reduces the time taken to document the solutions. The requirement management app allows the user to effectively trace the requirements from the moment it is captured to how it is captured into the design. The documentation of the solution can be done in multiple ways but in this project the documentation is done in a manner to suit the interests of designers and product managers.

7.2 RECOMMENDATIONS

Further research needs to be carried out on mathematical methods that can be used to reduce the number of parts further. The proposed manufacturing methods need to be evaluated with respect to performance and economics to further validate the proposal. Further steps needs to be taken to implement a product architecture for the engine compartment. If the product architecture of the engine bay is established for different product categories, a clear understanding of the variables which affect the design of the hood can be obtained. Future designs can make use of the engine bay architecture to define the variables which drive the design of the hood.

With respect to the 3DX platform, other features of the software with respect to manufacturing can be used to demonstrate the manufacturing process of the proposed modular hood. The impact of different roles can also be emphasized in the same.

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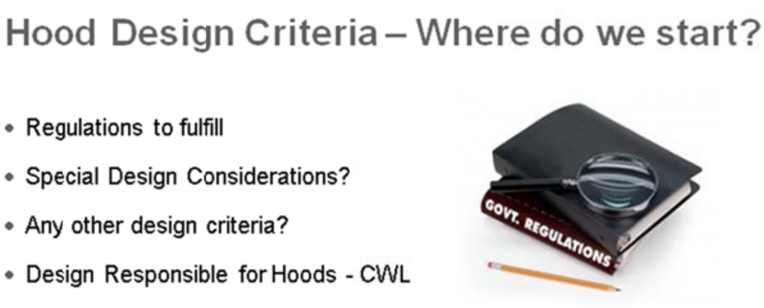
APPENDIX I

INTERVIEWEE LIST

INTERVIEWEES	PRODUCT CATEGORY	LOCATION
JOAKIM LUNDEN	ARTICULATED HAULERS, WHEEL LOADERS	BRAÅS, SWEDEN
MALVOOR SANTHOSHA	MOTOR GRADERS	SHIPPENSBERG, USA
STEVE LANAHAN	SOIL COMPACTORS	SHIPPENSBERG, USA
CRISTOPHE THEVENON	BACKHOE LOADERS	KONZ, GERMANY

INTERVIEW QUESTIONNAIRE – PPT SLIDES



INTERVIEW QUESTIONNAIRE – ANSWERS

SOIL COMPACTORS

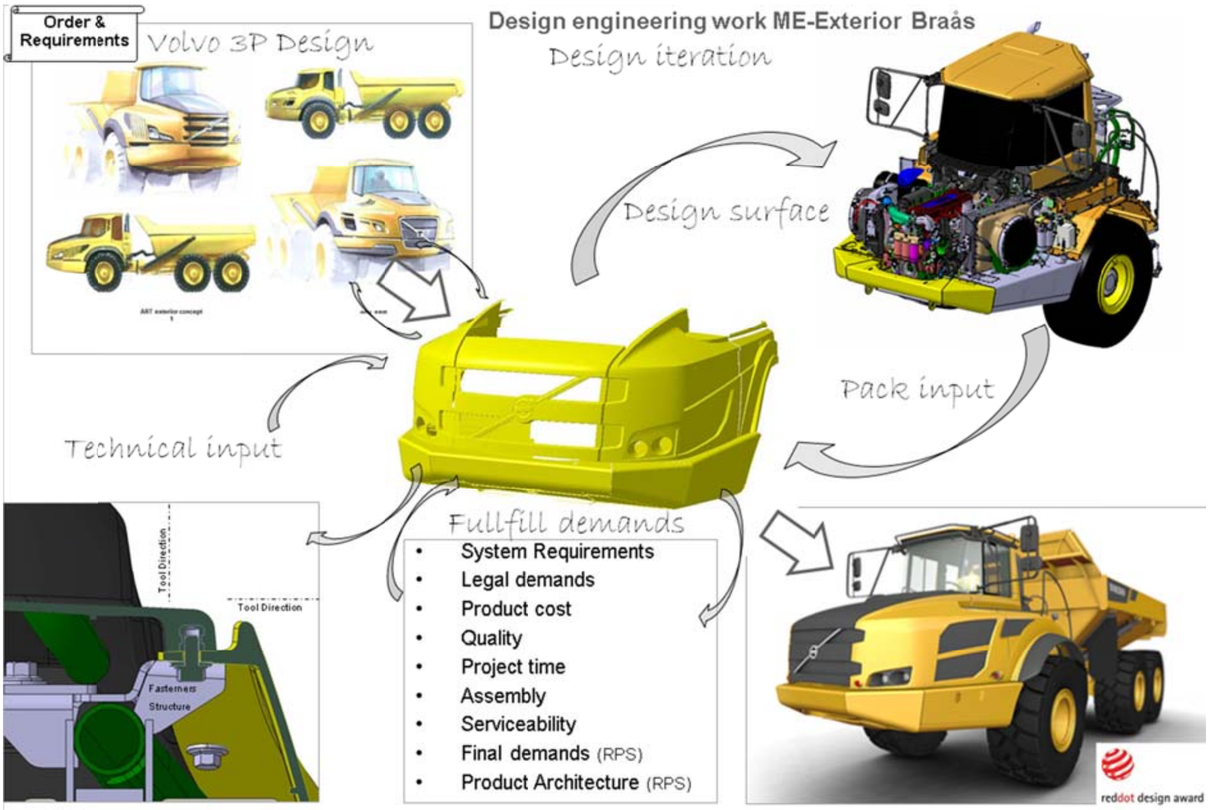
Design Considerations:

- 1m x 1m visibility (16mm clearance to visibility plane recommended0
- 1m x 1.5m visibility (no issues if 1x1 is met)
- 25mm general clearance between hood and all nearby components
- Hood must stay open under 18 mph wind load (prop rod, locking actuator, gas spring locking sleeve)
- Vibration loads (45 Hz for soil compaction, 70 Hz for asphalt compaction); peak vibration loads are achieved during vibe spin-up. Reinforcement is included to prevent cracking in front corners of hood (near heat shield).
- Styling requirements – from product design (A surface, badge and slash, mesh)
- Cost (part and tooling)
- Lifting points for removal/installation of hood on machine
- Actuator/gas springs
- System for holding hood closed (latch, locking actuator)
- Sound/heat absorption material
- Sealing for interfaces of hood with frame/cab
- Hinges, direction of hood hinging
- Clearance to cab when hood is open (hood cannot contact cab, 75mm minimum clearance required)
- 2 options: standard (intake mesh) and precleaner stack
- Air duct for air intake
- Highest surface finish requirements of all parts on machine
- Hood must be UV and fade resistant (2000 hours required)
- Water collection is not permitted during shipping, storage, and installed on machine. Drainage must be provided; water cannot drain onto electrical components
- Maximum 30 lbf lift/50 lbf pull down forces (if operator input is required for hood open/closing)
- Maximum 1900mm handle height with hood open
- Serviceability (air cleaner removal, cooling package access, fluid reservoirs, filters, test ports)

Interfaces:

- Air cleaner – bellows
- Cooling package – bulb seal
- Rear frame – bulb seal/latch/bump stop
- Heat shield – bulb seal
- Hood support – hinges/actuator

WHEEL LOADER AND ARTICULATED HAULERS



APPENDIX II

GENERAL REQUIREMENT STRUCTURE

CATEGORY	MODEL	PART	Design Requirements													Legal Requirements		
			Clearence Requirements						Ergonomic Requirements						Special Requirements	Visibility	Wind Speed	
			General Clearence		CAB		ARM		Lift force		Pull down force		Handle height					
			Value	Affected Parts	Value	Affected Parts	Value	Affected Parts	Value	Affected Parts	Value	Affected Parts	Value	Affected Parts			Value	Affected Parts
SC	SD25	HOOD_FRONT	25mm	X	75mm		30mm	X	30lbf	X	50lbf	X	1900mm	X	NO WATER SEEPAGE INTO ENGINE COMPARTMENT THROUGH AIR INTAKE, VIBRATION REQUIREMENT OF 45HZ	ISO 5006	18MPH	X
		HOOD_LH		X				X		X		X						X
		HOOD_RH		X				X		X		X						X
		HOOD_TOP		X						X		X		X				X
		HOOD_SS		X						X		X						X
	SD45	HOOD_FRONT		X				X		X		X		X				X
		HOOD_LH		X				X		X		X						X
		HOOD_RH		X				X		X		X						X
		HOOD_TOP		X						X		X		X				X
		HOOD_SS		X						X		X						X
	SD70	HOOD_FRONT		X				X		X								X
		HOOD_LH		X				X		X								X
		HOOD_RH		X				X		X								X
		HOOD_TOP		X						X								X
		HOOD_SS		X						X								X
	SD75	HOOD_FRONT		X		X		X		X								X
		HOOD_LH		X		X		X		X								X
		HOOD_RH		X		X		X		X								X
		HOOD_TOP		X		X				X								X
		HOOD_SS		X						X								X
	SD115	HOOD_FRONT		X		X		X		X								X
		HOOD_LH		X		X		X		X								X
		HOOD_RH		X		X		X		X								X
		HOOD_TOP		X		X				X								X
		HOOD_SS		X						X								X
	SD160	HOOD_FRONT		X				X		X								X
		HOOD_LH		X				X		X								X
		HOOD_RH		X				X		X								X
		HOOD_TOP		X						X								X
		HOOD_SS		X						X								X
BHL	BL60B-BL70B	HOOD_FRONT	30-40mm		NA		30mm		NA		NA		NA		NA	ISO 5006	8m/s	X
		HOOD_LH		X		X		X		X		X						X
		HOOD_RH		X		X		X		X		X						X
		HOOD_TOP		X		X				X		X		X				X
		HOOD_SS		X						X		X						X

CATEGORY	MODEL	PART	Design Requirements														Legal Requirements		
			Clearence Requirements						Ergonomic Requirements						Special Requirements		Visibility	Wind Speed	
			General Clearence		CAB		ARM		Lift force		Pull down force		Handle height						
			Value	Affected Parts	Value	Affected Parts	Value	Affected Parts	Value	Affected Parts	Value	Affected Parts	Value	Affected Parts				Value	Affected Parts
GWLO	L60H-L90H	HOOD_LH	25	X	NA	X	NA		NA	X	NA		NA		NA		ISO 5006	25m/s	X
		HOOD_RH		X		X				X									X
		HOOD_TOP		X		X				X									X
		HOOD_SS		X						X									X
	L110H-L120H	HOOD_FRONT		X						X									X
		HOOD_LH		X						X									X
		HOOD_RH		X						X									X
		HOOD_TOP		X						X									X
		HOOD_SS		X						X									X
	L150H-L180H	HOOD_FRONT		X						X									X
		HOOD_LH		X						X									X
		HOOD_RH		X						X									X
		HOOD_TOP		X						X									X
		HOOD_SS		X						X									X
	L220H-L250H	HOOD_FRONT		X						X									X
		HOOD_LH		X						X									X
		HOOD_RH		X						X									X
		HOOD_TOP		X						X									X
		HOOD_SS		X						X									X
CWL	L20F-L25F	HOOD_FRONT	25mm	X	NA	X	NA		NA	X	NA	X	NA		NA		ISO 5006	8m/s	X
		HOOD_LH		X		X				X		X							X
		HOOD_RH		X		X				X		X							X
		HOOD_TOP		X		X				X		X							X
		HOOD_SS		X						X		X							X
	L30G-L35G	HOOD_FRONT		X		X				X		X							X
		HOOD_LH		X		X				X		X							X
		HOOD_RH		X		X				X		X							X
		HOOD_TOP		X		X				X		X							X
		HOOD_SS		X						X		X							X
	L45G-L50G	HOOD_FRONT		X		X				X									X
		HOOD_LH		X		X				X									X
		HOOD_RH		X		X				X									X
		HOOD_TOP		X		X				X									X
		HOOD_SS		X						X									X
MG	G930C	HOOD_FRONT	25mm	X	NA		NA		NA	X	NA		NA		NA		ISO 5006	8m/s	X
		HOOD_LH		X						X									X
		HOOD_RH		X						X									X
		HOOD_TOP		X						X									X
		HOOD_SS		X						X									X
	G940-G960C	HOOD_FRONT		X						X									X
		HOOD_LH		X						X									X
		HOOD_RH		X						X									X
		HOOD_TOP		X						X									X
		HOOD_SS		X						X									X

CATEGORY	MODEL	PART	Design Requirements														Legal Requirements		
			Clearence Requirements						Ergonomic Requirements						Special Requirements	Visibility	Wind Speed	
			General Clearence		CAB		ARM		Lift force		Pull down force		Handle height					
			Value	Affected Parts	Value	Affected Parts	Value	Affected Parts	Value	Affected Parts	Value	Affected Parts	Value	Affected Parts			Value	Affected Parts
AH	A25F-A30F	HOOD_LH	25mm	X	NA		NA-		NA	X	NA		NA		NA	ISO 5006	8m/s	X
		HOOD_RH		X						X								X
		HOOD_TOP		X						X								X
		HOOD_SS		X						X								X
	A35F-A40F	HOOD_FRONT		X						X								X
		HOOD_LH		X						X								X
		HOOD_RH		X						X								X
		HOOD_TOP		X						X								X
		HOOD_SS		X						X								X

INTERFACE DEFINITION

CATEGORY	MODEL	PART	Dimension Drivers											
			Engine Type	Frame	Exhaust Treatment system	CAB	Radiator Housing	Cooling package	Exhaust support structure	Tyre	Fan Shroud	Air Clleaner	Fuel Tank	Wheel Housing
SC	SD25	HOOD_FRONT		X							X			
		HOOD_LH		X		X			X	X	X			X
		HOOD_RH		X		X			X	X	X			X
		HOOD_TOP		X	X	X			X		X			
		HOOD_SS	X	X	X				X		X			
	SD45	HOOD_FRONT		X							X			
		HOOD_LH		X		X			X	X	X			X
		HOOD_RH		X		X			X	X	X			X
		HOOD_TOP		X	X	X			X		X			
		HOOD_SS	X	X	X				X		X			
	SD70	HOOD_FRONT		X							X			
		HOOD_LH		X		X				X	X			X
		HOOD_RH		X		X				X	X			X
		HOOD_TOP		X	X	X					X			
		HOOD_SS	X	X	X						X			
	SD75	HOOD_FRONT		X		X					X			
		HOOD_LH		X		X				X	X			X
		HOOD_RH		X		X				X	X			X
		HOOD_TOP		X	X	X					X			
		HOOD_SS	X	X	X						X			
	SD115	HOOD_FRONT		X		X					X			
		HOOD_LH		X		X				X	X			X
		HOOD_RH		X		X				X	X			X
		HOOD_TOP		X	X	X					X			
		HOOD_SS	X	X	X						X			
	SD160	HOOD_FRONT		X							X			
		HOOD_LH		X		X				X	X			X
		HOOD_RH		X		X				X	X			X
		HOOD_TOP		X	X	X					X			
		HOOD_SS	X	X	X						X			
BHL	BL60B-BL70	HOOD_FRONT												
		HOOD_LH		X		X			X	X	X			X
		HOOD_RH		X		X			X	X	X			X
		HOOD_TOP		X	X	X			X		X			
		HOOD_SS	X	X	X				X		X			
GWLO	L60H-L90H	HOOD_FRONT		X		X					X			
		HOOD_LH		X		X			X	X	X			X
		HOOD_RH		X		X			X	X	X			X
		HOOD_TOP		X	X	X			X		X			
		HOOD_SS	X	X	X				X		X			
	L110H-L120H	HOOD_FRONT		X							X			
		HOOD_LH		X		X			X	X	X			X
		HOOD_RH		X		X			X	X	X			X
		HOOD_TOP		X	X	X			X		X			
		HOOD_SS	X	X	X				X		X			
	L150H-L180H	HOOD_FRONT		X							X			
		HOOD_LH		X		X			X	X	X			X
		HOOD_RH		X		X			X	X	X			X
		HOOD_TOP		X	X	X			X		X			
		HOOD_SS	X	X	X				X		X			
	L220H-L250H	HOOD_FRONT		X							X			
		HOOD_LH		X		X			X	X	X			X
		HOOD_RH		X		X			X	X	X			X
		HOOD_TOP		X	X	X			X		X			
		HOOD_SS	X	X	X				X		X			

CATEGORY	MODEL	PART	Dimension Drivers											
			Engine Type	Frame	Exhaust Treatment system	CAB	Radiator Housing	Cooling package	Exhaust support structure	Tyre	Fan Shroud	Air Clleaner	Fuel Tank	Wheel Housing
CWL	L20F-L25F	HOOD_FRONT		X		X		X			X			
		HOOD_LH		X		X		X	X	X	X			X
		HOOD_RH		X		X		X	X	X	X			X
		HOOD_TOP		X	X	X		X	X		X			
		HOOD_SS	X	X	X				X		X			
	L30G-L35G	HOOD_FRONT		X		X		X			X			
		HOOD_LH		X		X		X	X	X	X			X
		HOOD_RH		X		X		X	X	X	X			X
		HOOD_TOP		X	X	X		X	X		X			
		HOOD_SS	X	X	X				X		X			
	L45G-L50G	HOOD_FRONT		X		X		X			X			
		HOOD_LH		X		X		X	X	X	X			X
		HOOD_RH		X		X		X	X	X	X			X
		HOOD_TOP		X	X	X		X	X		X			
		HOOD_SS	X	X	X				X		X			
MG	G930C	HOOD_FRONT		X		X					X			
		HOOD_LH		X		X					X			X
		HOOD_RH		X		X					X			X
		HOOD_TOP		X	X	X					X			
		HOOD_SS	X	X	X						X			
	G940-G960	HOOD_FRONT		X		X					X			
		HOOD_LH		X		X					X			X
		HOOD_RH		X		X					X			X
		HOOD_TOP		X	X	X					X			
		HOOD_SS	X	X	X						X			
AH	A25F-A30F	HOOD_FRONT		X		X					X			
		HOOD_LH		X		X	X				X		X	X
		HOOD_RH		X		X	X				X	X		X
		HOOD_TOP			X	X	X				X			
		HOOD_SS	X	X	X		X				X			
	A35F-A40F	HOOD_FRONT		X		X					X			
		HOOD_LH		X		X	X				X		X	X
		HOOD_RH		X		X	X				X	X		X
		HOOD_TOP			X	X	X				X			
		HOOD_SS	X	X	X		X				X			

APPENDIX III

REQUIREMENT MANAGEMENT SUMMARY – COMPLETE – MODULAR HOOD

Name	Revision
Hood Design	2
Design Requirements	2
Clearence Requriements	1
General Clearence for components	A
General Clearence of 25mm	A
General Clearence of 30-40mm	A
Cab Clearence	A
Clearence of 75mm	A
Arm Clearence	A
Clearence of 30mm	A
Ergonomic Requriements	1
Lift Force of Hood	A
Pull Down Force of Hood	A
Height of Hood handle	A

Name	Revision
Special Requriements	2
Water Leakage into air intake requirement	1
No water leakage into engine compartm	A
Vibration Load Requirement of 70 Hz	A
Functtional Allocation	1
Accomodate Engine Air Intake	A
Accomodate Engine Exhaust	A
Accomodate Cooling Intake	A
Accomodate Cooling Exhausr	A
Hinge Position	1
Hood Hinge below the front grille	A
Hood Hinge near the top panel	A

Name	Revision
Hood Hinge near the top panel	A
Geographical Requrirement	2
Operate in North America	A
Operate in South America	A
Operate in Europe	A
Operate in Asia	A
Operate in Africa	A
Legal Requirements	2
General visibility	1
Satisfy ISO 5006	A
Wind speed Requirements	1
Hood Should stay open at windspeed of	A
Hood Should stay open at windspeed of	A
Hood Should stay open at windspeed of	A
Operation Type	2
Earth Moving	A
Compaction	A
Hauling	A

RELATIONSHIP BETWEEN REQUIREMENTS AND CONFIGURATION OPTIONS

Requirement Name	Title	Rev	State	Con	Feature Name	Type	Rev
Accomodate Cooling Exhausr		A	Release		Cooling Exhaust Position	Configuration Feature	A
Accomodate Cooling Intake		A	Release		Cooling Inlet Position	Configuration Feature	A
Accomodate Engine Air Intake		A	Release		Engine Intake Position	Configuration Feature	A
Accomodate Engine Exhaust		A	Release		Engine Exhaust Position	Configuration Feature	A
Arm Clearence		A	Release		Vehicle Category	Configuration Feature	A
Cab Clearence		A	Release		Vehicle Category	Configuration Feature	A
Compaction		A	Release		Vehicle Type	Configuration Feature	A
General Clearence for components		A	Release		Vehicle Category	Configuration Feature	A
Hauling		A	Release		Vehicle Type	Configuration Feature	A
Height of Hood handle		A	Release		Vehicle Category	Configuration Feature	A
Hood Hinge below the front grille		A	Release		Hood Opening Style	Configuration Feature	A
Hood Hinge near the top panel		A	Release		Hood Opening Style	Configuration Feature	A
Hood Should stay open at windspeed of 18MPH		A	Release		Vehicle Category	Configuration Feature	A
Hood Should stay open at windspeed of 25m/s		A	Release		Vehicle Category	Configuration Feature	A
Hood Should stay open at windspeed of 8m/s		A	Release		Vehicle Category	Configuration Feature	A
Lift Force of Hood		A	Release		Vehicle Category	Configuration Feature	A
No water leakage into engine compartment from top pa		A	Release		Vehicle Category	Configuration Feature	A
Operate in Africa		A	Release		Market	Configuration Feature	A
Operate in Asia		A	Release		Market	Configuration Feature	A
Operate in Europe		A	Release		Market	Configuration Feature	A
Operate in North America		A	Release		Market	Configuration Feature	A
Operate in South America		A	Release		Market	Configuration Feature	A
Pull Down Force of Hood		A	Release		Vehicle Category	Configuration Feature	A

CONFIGURATION FEATURES AND OPTIONS – COMPLETE – MODULAR HOOD

Display Name	Name	Type	State	Seq	Single/ I	Inherited	Effectivity
Modular Hood A	Modular Hood A	Hardware Pro...	Review				
Engine Exhaust Position A	Engine Exhau...	Configuration ...	Review	5	Single		[Jan 1, 2014-Jan 1, 2016]
Engine Exhaust on Top Panel	Engine Exhau...	Configuration ...	Exists	1	Single		[Jan 1, 2014-Jan 1, 2016]
No exhaust opening on hood	No exhaust o...	Configuration ...	Exists	1	Single		[Jan 1, 2014-Jan 1, 2016]
Cooling Exhaust Position A	Cooling Exha...	Configuration ...	Review	7	Single		[Jan 1, 2014-Jan 1, 2016]
Cooling Vent on side panels	Cooling Vent ...	Configuration ...	Exists	1	Single		[Jan 1, 2014-Jan 1, 2016]
Cooling Vent absent	Cooling Vent ...	Configuration ...	Exists	1	Single		[Jan 1, 2014-Jan 1, 2016]
Cooling Vent on top panel	Cooling Vent ...	Configuration ...	Exists	1	Single		[Jan 1, 2014-Jan 1, 2016]
Engine Intake Position A	Engine Intake...	Configuration ...	Review	4	Single		[Jan 1, 2014-Jan 1, 2016]
Engine Intake on Top	Engine Intake...	Configuration ...	Exists	1	Single		[Jan 1, 2014-Jan 1, 2016]
Engine Intake on Side Panels	Engine Intake...	Configuration ...	Exists	1	Single		[Jan 1, 2014-Jan 1, 2016]
Engine Intake absent	Engine Intake...	Configuration ...	Exists	1	Single		[Jan 1, 2014-Jan 1, 2016]
Vehicle Category A	Vehicle Categ...	Configuration ...	Review	2	Single		[Jan 1, 2014-Jan 1, 2016]
Haulers	Haulers	Configuration ...	Exists	2	Single		[Jan 1, 2014-Jan 1, 2016]
Road Machineries	Road Machin...	Configuration ...	Exists	3	Single		[Jan 1, 2014-Jan 1, 2016]
Earth Movers	Earth Movers	Configuration ...	Exists	1	Single		[Jan 1, 2014-Jan 1, 2016]
Compactors	Compactors	Configuration ...	Exists	4	Single		[Jan 1, 2014-Jan 1, 2016]

Display Name	Name	Type	State	Seq	Single/ I	Inherited	Effectivity
Vehicle Category A	Vehicle Categ...	Configuration ...	Review	2	Single		[Jan 1, 2014-Jan 1, 2016]
Engine Type A	Engine Type A	Configuration ...	Review	1	Single		[Jan 1, 2014-Jan 1, 2016]
D16	D16	Configuration ...	Exists	9	Single		[Jan 1, 2014-Jan 1, 2016]
D3.8	D3.8	Configuration ...	Exists	2	Single		[Jan 1, 2014-Jan 1, 2016]
D9	D9	Configuration ...	Exists	6	Single		[Jan 1, 2014-Jan 1, 2016]
D6	D6	Configuration ...	Exists	4	Single		[Jan 1, 2014-Jan 1, 2016]
D11	D11	Configuration ...	Exists	7	Single		[Jan 1, 2014-Jan 1, 2016]
D8	D8	Configuration ...	Exists	5	Single		[Jan 1, 2014-Jan 1, 2016]
D4	D4	Configuration ...	Exists	3	Single		[Jan 1, 2014-Jan 1, 2016]
D3	D3	Configuration ...	Exists	1	Single		[Jan 1, 2014-Jan 1, 2016]
D13	D13	Configuration ...	Exists	8	Single		[Jan 1, 2014-Jan 1, 2016]
Hood Opening Style A	Hood Opening...	Configuration ...	Review	8	Single		[Jan 1, 2014-Jan 1, 2016]
Towards the Cab	Towards the Cab	Configuration ...	Exists	1	Single		[Jan 1, 2014-Jan 1, 2016]
Away from the Cab	Away from th...	Configuration ...	Exists	2	Single		[Jan 1, 2014-Jan 1, 2016]
Market A	Market A	Configuration ...	Review	3	Single		[Jan 1, 2014-Jan 1, 2016]
Asia	Asia	Configuration ...	Exists	4	Single		[Jan 1, 2014-Jan 1, 2016]
North America	North America	Configuration ...	Exists	1	Single		[Jan 1, 2014-Jan 1, 2016]
Europe	Europe	Configuration ...	Exists	3	Single		[Jan 1, 2014-Jan 1, 2016]
South America	South America	Configuration ...	Exists	2	Single		[Jan 1, 2014-Jan 1, 2016]
Africa	Africa	Configuration ...	Exists	5	Single		[Jan 1, 2014-Jan 1, 2016]
Cooling Inlet Position A	Cooling Inlet ...	Configuration ...	Review	6	Single		[Jan 1, 2014-Jan 1, 2016]
Cooling inlet on Top panel	Cooling inlet o...	Configuration ...	Exists	1	Single		[Jan 1, 2014-Jan 1, 2016]
Cooling inlet on side panel	Cooling inlet o...	Configuration ...	Exists	1	Single		[Jan 1, 2014-Jan 1, 2016]

CONFIGURATION RULES SUMMARY

Name ▲	Left Expression	Compatibility	Right Expression	Error Message
Cooling exhaust side	"Cooling Exhaust Position::A~Cooling Vent on side panels"	Incompatible	"Cooling Inlet Position::A~Cooling inlet on side panel"	Cooling exhaust on the side requires the inlet to be on top and front
Cooling Top-Top	"Cooling Exhaust Position::A~Cooling Vent on top panel"	Incompatible	"Cooling Inlet Position::A~Cooling inlet on Top panel"	Inlet and exhaust cannot be on the same direction
Haulers compatibility	"Engine Intake Position::A~Engine Intake absent"	Requires	"Engine Exhaust Position::A~No exhaust opening on hood"	Haulers donot have engine inlet and exhausts
Hood Opening compatibility 1	"Hood Opening Style::A~Away from the Cab"	Requires	"Vehicle Category::A~Earth Movers"	Wheel Loaders have Hoods opening away from the cab in order to reduce their overall height in opened condition
Inclination rule	"Cooling Inlet Position::A~Cooling inlet on side panel"	Incompatible	"Cooling Exhaust Position::A~Cooling Vent absent"	Cooling air from sides needs to be vented out either in the front or top
Vibration Incompatibility	"Vibrational Requirements::A~NA"	Incompatible	"Vehicle Category::A~Compactors"	Vibratory requirements not applicable to the selected categories
Vibration Requirements Compatibility	"Vibrational Requirements::A~45HZ" OR "Vibrational Requirements::A~70HZ"	Requires	"Vehicle Category::A~Compactors"	Vibratory Requirements are compatible only with Compactors
WLO Engine Compatibility	"Engine Intake Position::A~Engine Intake on Side Panels"	Requires	"Engine Exhaust Position::A~Engine Exhaust on Top Panel"	Wheel Loaders Require the exhaust outlet on the top panel as it has the Exhaust after treatment on the top of the engine on the hood
WLO hood incompatibility	"Vehicle Category::A~Compactors" OR "Vehicle Category::A~Haulers" OR "Vehicle Category::A~Road Machineries"	Incompatible	"Hood Opening Style::A~Away from the Cab"	All vehicle categories apart from WLO have hoods opening towards the cab

MARKETING PREFERENCES SUMMARY

Name ▲	Marketing Preference Condition	Configuration Choices
Compactor Engines	"Vehicle Category::A~Compactors"	"Engine Type::A~D3.8" AND "Engine Type::A~D4" AND "Engine Type::A~D6"
Cooling exhaust compatibility - Earth Movers 1	("Engine Type::A~D6" OR "Engine Type::A~D8") AND "Vehicle Category::A~Earth Movers"	"Cooling Exhaust Position::A~Cooling Vent on top panel" AND "Cooling Inlet Position::A~Cooling inlet on side panel"
Cooling exhaust compatibility - Earth Movers 2	"Engine Type::A~D13" AND "Vehicle Category::A~Earth Movers"	"Cooling Exhaust Position::A~Cooling Vent on side panels" AND "Cooling Inlet Position::A~Cooling inlet on Top panel"
Cooling exhaust compatibility - Soil Compactors	("Engine Type::A~D3.8" OR "Engine Type::A~D4" OR "Engine Type::A~D6") AND "Vehicle Category::A~Compactors"	"Cooling Exhaust Position::A~Cooling Vent absent" AND "Cooling Inlet Position::A~Cooling inlet on Top panel"
Earth Mover Engines	"Vehicle Category::A~Earth Movers"	"Engine Type::A~D13" AND "Engine Type::A~D6" AND "Engine Type::A~D8" AND "Engine Type::A~D3"
Hauler Engines	"Vehicle Category::A~Haulers"	"Engine Type::A~D11" AND "Engine Type::A~D13" AND "Engine Type::A~D16"
Hauler Side Panel Compatibility	"Vehicle Category::A~Haulers"	"Cooling Exhaust Position::A~Cooling Vent on side panels" AND "Cooling Inlet Position::A~Cooling inlet on Top panel"
Road Machineries engines	"Vehicle Category::A~Road Machineries"	"Engine Type::A~D8" AND "Engine Type::A~D9"