Modularity Techniques in Commercial Vehicle

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***Abstract*— Automobile manufacturers face lot of challenges, which includes, offering more vehicle variants based on customer demands with limited resource and costs, new market penetration, new legislative norms, competition etc. The present vehicle architecture is very rigid and it would require a relook at the design every time a new requirement is put forth and comes with a cost penalty, in terms of resources, and in addition will have a high lead time to market.**

To tackle the above challenges without the disadvantages mentioned above, the paper proposes modular vehicle architecture and few of its techniques, which would enable the Vehicle to adapt to different specifications.

Keywords*— *Modularity, modular techniques, commercial vehicle, modular design approach, modular interface, modular design

I. INTRODUCTION

Increasing competition and global expansion in the automotive industry have created a need to provide a wide variety of products to customers according to their requirements. This is especially true for the commercial vehicle segment. The requirements may be region specific standards, adaptations or luxury needs etc. The present method of designing a commercial vehicle has been in existence for decades and has many drawbacks which have been discussed in detail in next section.

There is an imminent need to react faster to changing customer requirements and modularity has been proven to be effective solution for such a problem.

A modular automobile build will benefit the commercial vehicle industry in many ways including; reduction in tooling cost, less manpower training, less engineering effort and hence cost, lesser inventory, reducing time to market and huge customization.

II. CONVENTIONAL DESIGN APPROACH

In the existing design architecture, for each new requirement, the design has to be modified and a new aggregate combination is offered as solution, this may be due to one of the several reasons as listed below:

A. Lack of common topology: Between different vehicle-segments the overall topology of the vehicle changes. This results in a completely a new set of components for each vehicle segment which in turn adds to the cost.

B. No common defined Interfaces: Interacting components often do not have common interfaces, which results in different parts and different assembly procedures which will add to higher design lead time and assembly time.

C. No common defined aggregate position: Between different segments and application of vehicles, the positions of aggregates vary resulting in change in topology of the vehicle. This in turn adds to no. of parts, increases cost and increased design lead time.

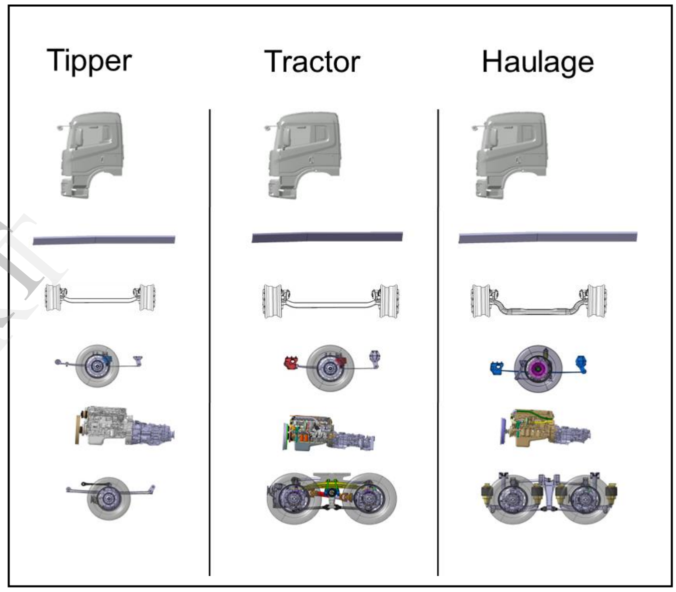

Figure 1.Conventinal design approach

Conventional approach is not meant to have interchangeability between the verticals, (refer figure.1) which results in rigid design architecture, it means, specific aggregate is used with only a particular vertical alone, say tipper, tractor, haulage and special application. Whenever a new vehicle requirement is sought, new vertical has to be in place which creates problem to the organization with high inventory, more lead time and more resource deployment.

III. NEED FOR CHANGE IN THE CONVENTIONAL APPROACH

A. Region specific needs:

Design of vehicle often has to cater to a number of local market specific requirements Eg) Luxurious cabs for European trucks whereas economic cabs for Asian markets to satisfy the region based needs. With the existing design architecture, it takes a longer time to address the needs as the design needs to be worked out from scratch.

B. Market Dynamics:

The present market scenario is constantly changing. New legislative requirements are often imposed in various markets for emission, safety and vehicular loads. In commercial vehicle segment, especially, new vehicle load segments, New vehicle configurations are being created Eg) In a market where 16T which used to have higher volumes, new higher tonnage segments 25T, 31T suddenly became hugely popular, and where engine power ratings used to be in the range 160-230hp the 270-300 hp range looms large in Asian Market.

C. Competition:

Presence of domestic and Global players, pose a bigger design challenge, which challenges the design in terms of cost, quality and reliability in addition to the price pressure posed by competitors.

The present method will not be able to overcome all these shortcomings. A modular architecture is an effective solution to overcome the aforementioned disadvantages.

IV. MODULARITY

Modular vehicle design architecture keeps the cost of the vehicle low. This is not only because it keeps down the number of components (yielding economies of scale), but also because the modular product system enables to develop new components without having to change other components at the same time. Assuming that the system can reduce the number of components by 50 percent, it helps in lowering costs for research and development by 30 to 50 percent, production by about 10 percent and sales and service by about 30 percent (refer figure no: 2).

To offer greater product variations at lower costs, many companies employ a modular strategy that explicitly leverages and reuses existing product design ideas and materials.

Modular design offers an efficient method for mass customization, enabling multiple product variations while keeping cost low. Especially in turbulent economic times with unpredictable customer behavior, R&D teams can reconfigure products quickly to react to changing customer needs (refer figure no: 3). Companies use different definitions of modular design depending on their specific organizational context.
Modular design facilitates the design of modular product architectures and/or the creation of modular manufacturing processes.

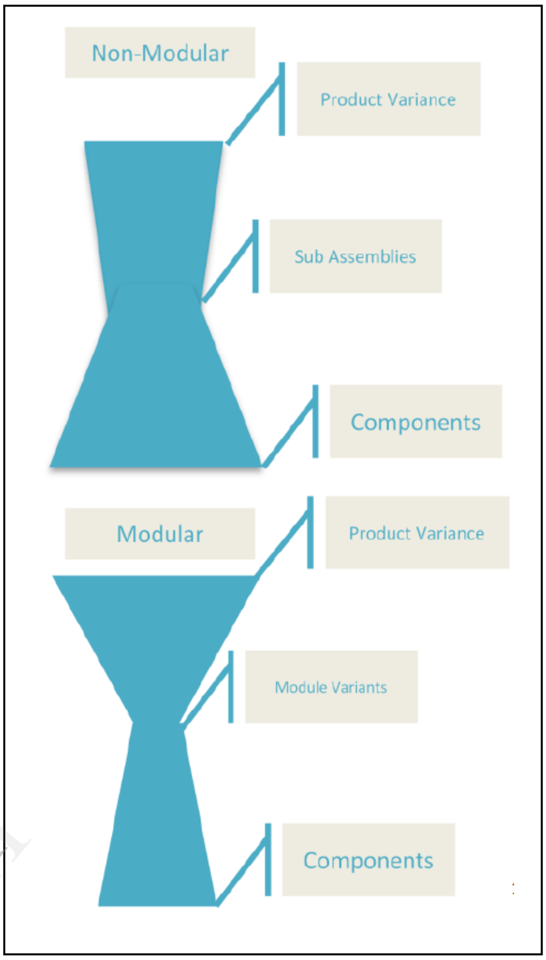

Figure 2.Graphical representation of Non modular product and modular product difference [3].

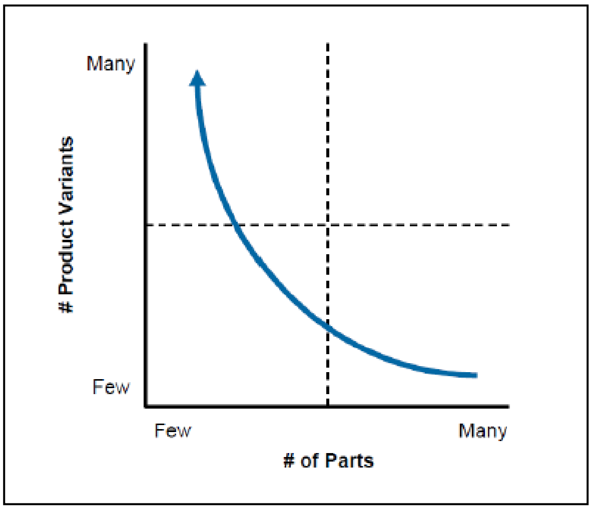

Figure 3.Product variants vs. part number [3].

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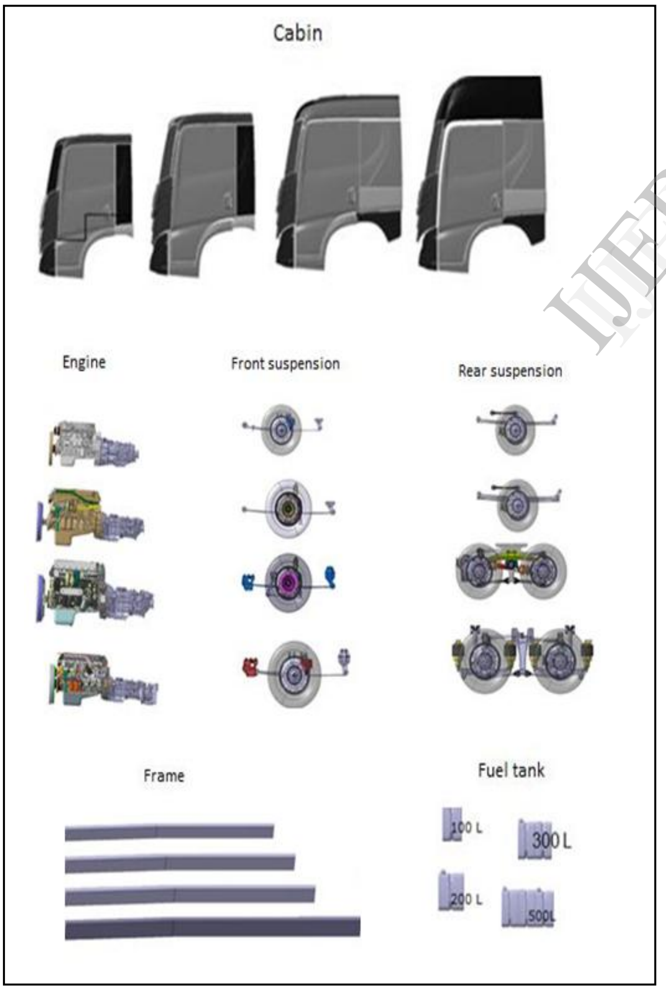
V. MODULARITY TECHNIQUES

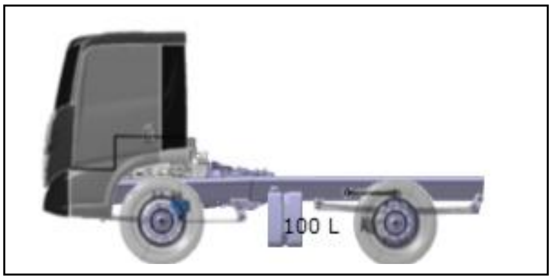
Modular design approach provides more variants and fulfills new market requirements of vehicles within the aggregate library by mix and match techniques (refer figure no: 4).

To enable modular architecture in an automobile, there are few techniques that can be applied, to maximize modularity.

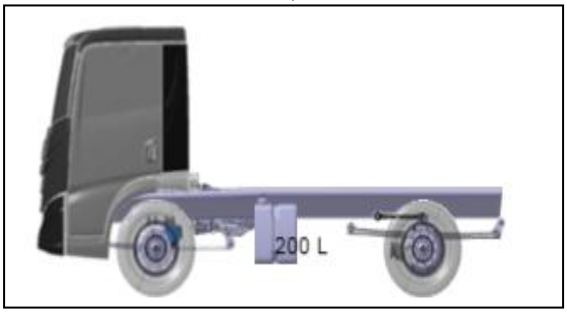
The fundamental principles behind these techniques are:

1. Study the vehicle requirements/Gather customer needs that completely to be included for modular vehicle build.
2. Break assembly into discrete modules
3. Ensuring flexibility in Modules for easy interchangeability
4. Providing well-defined interfaces.
5. Split vehicle into fixed and varying segments

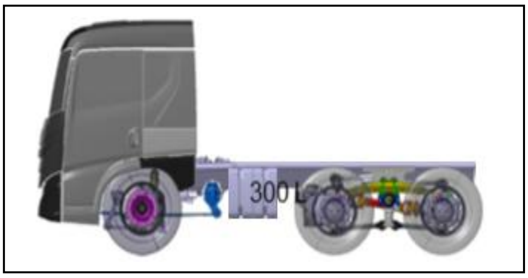




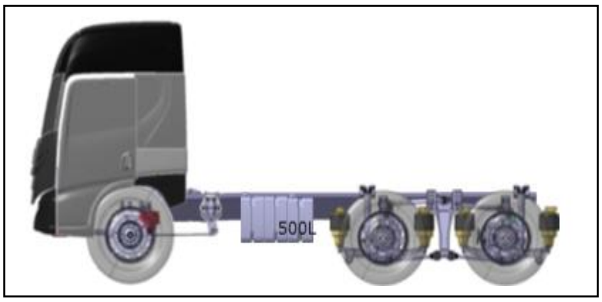
4x2 Tractor



4x2 Haulage from 4x2 Tractor; wheel base extension, fuel tank capacity change, cab type and frame



6x4 Tractor from 4x2 Haulage; Addition of rear axle, change in rear suspension, Fuel tank capacity change, cab type and frame



6x4 Haulage from 6x4 Tractor; change in rear suspension, Fuel tank, cab type and frame.

Figure 4.Modular design approach

1. Study of Vehicle requirements/ Gather customer needs

Before beginning to design a vehicle for modular design, it is absolutely essential to study all the requirements i.e., which markets are these vehicles going to address, what legislations apply in that region, cost dynamics and operating dynamics, how long the new vehicle platform is going to exist and all the future requirements and legislations that would emerge etc. If there is one drawback of modularity, it is that once the systems are modularly made and placed, it is difficult to repackage the same. Hence all requirements need to be studied upfront.

2. Break assembly into discrete modules

One of the reasons as to why assembly procedures, inventory, handling and logistics are complex is because of the varying topology of similar systems used in the vehicle.

To reduce such complexity, the topology of the systems should remain same so that the assembly and handling becomes easy. Divide the system into small modules in such a way that, multiple combinations (variants) of the same can be created with varied performances. This approach can reduce the inventory and re-use of small modules more vigorously.

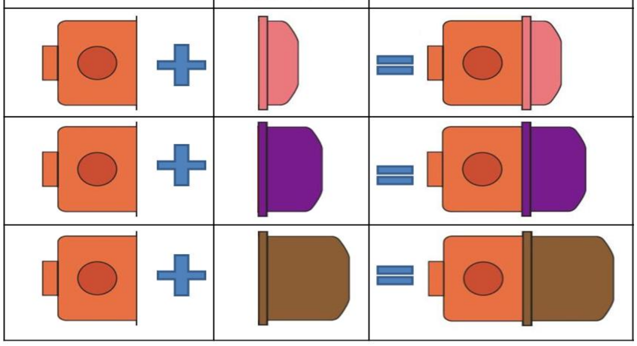
It is utmost essential that the functionality of part needs to be studied thoroughly, before splitting the aggregate for variants benefit. Two simple and specific examples are described below.

a. Air cleaner:

Air cleaner can be divided into two parts, top and bottom part, keeping the diameter of air cleaner same and changing the bottom cover depth to achieve the different capacity of air cleaner according to the engine capacity (Refer table no :1) . This may reduce the inventory and tool development cost and allows interchangeability.

Table 1.Air cleaner Top and bottom module

Same ϕ Top Cover	Varying depth Bottom Cover	Different Air Cleaner sizes



b. Exhaust system:

Exhaust muffler can be divided into 3 major parts such as left module, Centre module and right module(Refer figure:5),based on capacity of muffler the Centre module size varies and fits with same left and right module to attain the required muffler capacity.

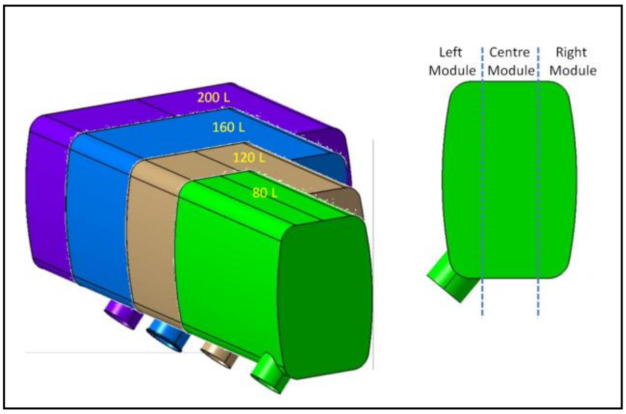


Figure 5.Muffler modules.

3. Flexibility to interchange the modules

The most important concept in modular design approach is to interchange modules (aggregates) easily in vehicle without affecting other aggregates. All interchangeable aggregates should be aligned to a common point, say; common defined coordinates, though its dimension can vary in the other direction, to a defined length and width.

Modules are defined as physical structures that have a one to one correspondence with functional structures [2]. One of the central problems in the creation of a modular product is the definition of the boundaries of the modules [5].

(E.g.1) Four different frame depth can be interchanged between LCV, ICV, MCV and HCV vehicles due to similar frame topology and hole pattern.

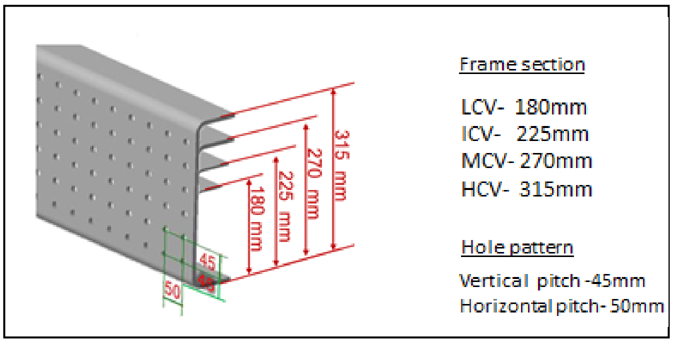


Figure 6. Frame section hole pattern modularity

(E.g.2) Different horse power engines located at common coordinate position (Refer figure: 7) which helps in interchanging them without doing change in chassis design.

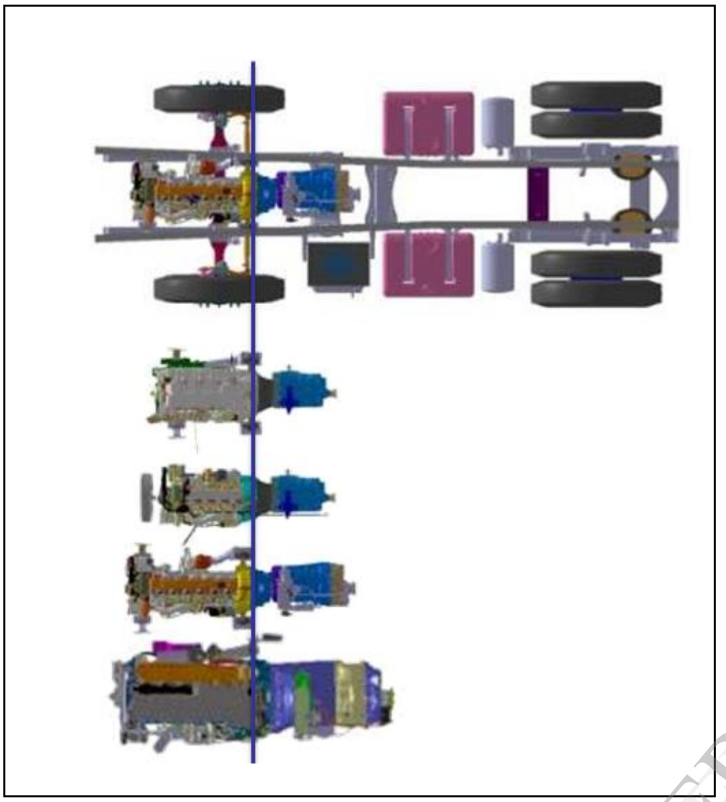


Figure 7.Interchangeable Powertrain modules.

The following are the advantages, which can be achieved by above technique:

i. Increase in vehicle variants

ii. Reducing piping variants & part numbers (Pneumatic & Hydraulic engine lines)

iii. Reducing electrical wiring variants & part numbers

iv. Reducing propeller shaft variants & part numbers

4. *Well defined interface:*

Most of the companies end up doing the mistake by designing the systems independently, without considering the various possible combinations of parts interacting with each other. This would result in many variants of the same functional part leading to repetitive design and validation work. The common interface signifies the common point between two aggregates, which helps to interchange the aggregates without much change in other aggregates in the chassis. Consider the example of an engine with engine interface system, the (figure: 8) may give an idea about the common interface and with what other aggregate, it can be applied.

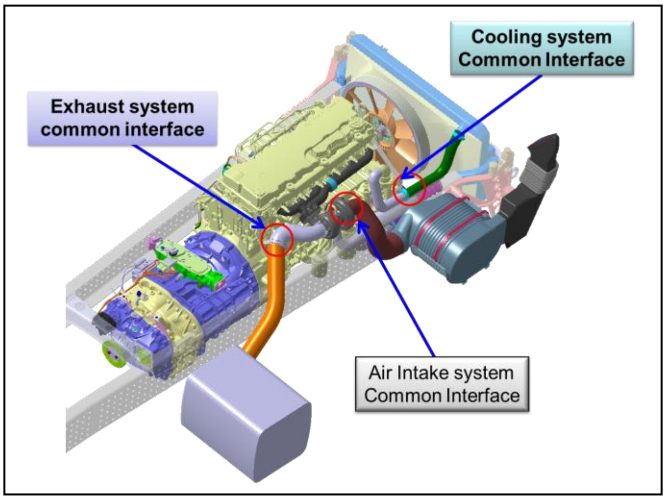


Figure 8.Engine interface point.

This approach can be applied between many aggregates:

a. Engine and Cooling system
b. Engine and Exhaust system
c. Engine and Air intake system
d. Cabin and Brake routings
e. Cabin and Electrical routings etc.

a. Engine and cooling system

Generally, cooling system varies according to the engine power rating and heat load. Low horse power to high horse power engines can be packaged in one chassis if one common interface point between cooling system and engine can be identified which will help in easy interchange between variants. The engine and cooling connecting pipes can meet at that common interface point (Refer figure: 9).

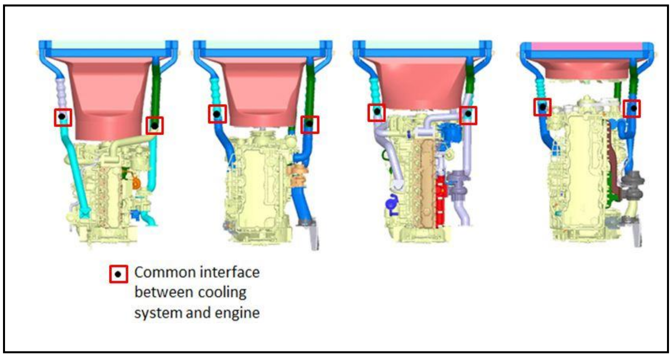


Figure 9.Various engine and cooling system arrangement.

5. *Split vehicle into fixed and varying segments:*

The vehicle chassis needs split into modules such that the common module stays the same and only the varying module changes, thereby a huge number of part numbers and hence cost can be reduced. An illustrative example of the same in figure no: 10 and 11.

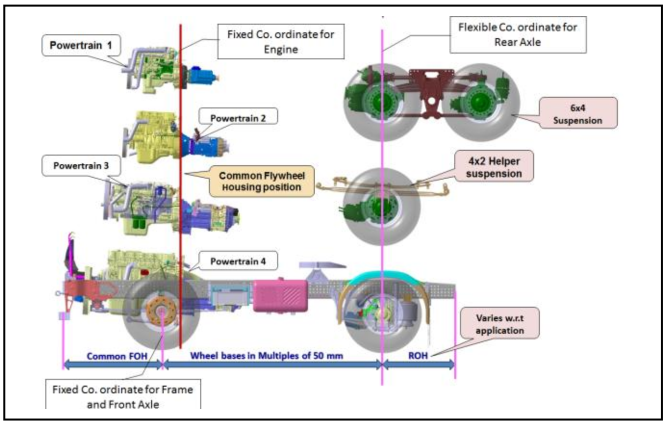


Figure 10.Fixed and Variable coordinates

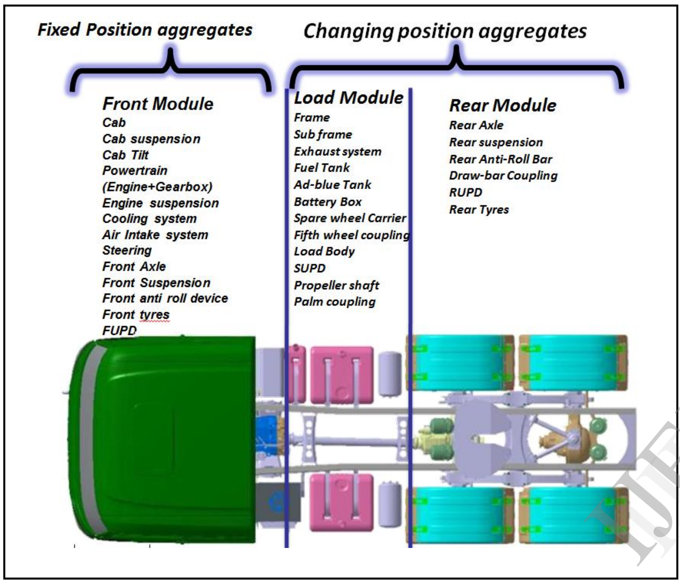


Figure 11.Fixed position aggregates and changing position aggregates

In a commercial vehicle, the vehicle wheel base and the axle configuration are the major variables of the vehicle. But the front module comprising the engine, front axle, cooling system, air intake system, cab etc. can be kept modularly packaged and can be isolated from packaging changes. This in turn reduces the changes that would be required to make a new vehicle which varies in terms of wheel bases, fuel tank capacities, rear suspension options and rear axle changes.

6. Providing only required aggregate size:

Unlike standardization where same size aggregates are used in all tonnages, modularity provides us an opportunity to specify the required aggregate size to suit specific vehicle requirement and tonnage, thereby reducing the cost without changing the common topology and interface.

Few examples are,

i. Frame section depth change according to tonnage
ii. Cooling size according to engine requirement
iii. Axle section change according to tonnage.

CONCLUSION:

The conventional method will not be able to meet the changing requirements and will result in higher lead times and higher cost. To offer greater product variations at lower costs, companies can employ a modular strategy that explicitly leverages and reuses same modules in many variants [1], By building the commercial vehicle using the modularity techniques discussed above, the following advantages can be obtained:

1. Greater product variety: The variety of the product gets multiplied with the help of modularity approach with lesser part numbers

2. Reduced cost of development: Since common parts are used in many modules, volume of individual parts will increase and there would be a reduction in part cost.

3. Mass customization: Modular product provides the flexibility to change the specification to customize and create huge variants and different customization.

4. Faster technological upgrading: Flexible product designs that allow a company to respond to changing markets and technologies by rapidly and inexpensively creating product variants derived from different combinations of existing or new modules

5. Increasing speed to market : Parallel development activities are possible once the interfaces between the modules have been defined, This reduces overall development time and resource requirements by eliminating the time-consuming redesign of components

6. Ease of maintenance, repair and Recycling: With modules, the operations of maintenance, repair and recycling become more trivial. For example, capacity of an air cleaner can be changed without affecting the engine and their arrangement on the vehicle.

7. Handle uncertainty: With modular architecture, market uncertainties can be managed very easily. When future consumer preferences are uncertain, building flexibility into the vehicle design to accommodate different possible aggregate configurations would be very essential.

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