CIRP Annals - Manufacturing Technology 60 (2011) 165–168

Contents lists available at ScienceDirect

CIRP Annals - Manufacturing Technology

journal homepage: http://ees.elsevier.com/cirp/default.asp

Product modularity and assembly systems: An automotive case study

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ARTICLE INFO

Keywords:
Modular design
Flexibility
Automotive BiW

ABSTRACT

Designing modular products offers a number of advantages. However, modularity may be challenging in terms of production and assembly. In this paper, the influence of product design modularity on assembly systems is investigated. A modular design from the automotive industry is presented and compared with a traditional design. The influence of modularity on the assembly system is discussed including attributes such as production rate, investment cost and product's delivery delay.

1. Introduction

Integral product architecture includes a complex, many-to-many mapping from functional elements to physical components and/or coupled interfaces between components. A modular architecture presents an one-to-one correspondence between modules and functions and specifies de-coupled interfaces between components [1]. Product modularity enables the easy generation of product families from a basic-platform design, by simply mixing and matching the various modules. Via this product variation a high degree of customization may be achieved [2]. Moreover, parts or modules carryover and reuse are also possible with modularity.

However, the product's structure also influences its production [3]. Manufacturing systems capable of producing in an agile manner all the product variants derived from a modular design, are required. Different design methodologies to derive such systems have been discussed in Refs. [4–6]. The key element of such systems is the integration of technologies such as flexible fixtures and tooling, multi-skilled workforce, redundant robots, sensing techniques, wireless technology, fixtureless assembly, automated robot calibration, flexible shifts, and flexible floor space [7].

The purpose of this paper is to investigate the effects of product modularity on the design, configuration and operation of assembly systems. As a case study an under-body structure of an automotive Body-in-White (BiW) has been selected. BiW in the automotive industry refers to a car body's sheet metal components that have been assembled together before painting. The under-body structure (Fig. 1) is one of the most critical components of an automotive BiW. Two alternative designs of an under-body structure, a modular and an integral one, are described. They allow the production of three under-body structure variants. The assembly systems for both designs are modelled and simulated. The different assembly configurations are then compared from the viewpoint of production responsiveness to demand, cumulative delays, estimated utilization rates and investment cost per product.

2. Modular versus integral design

The under-body structure carries and connects many significant car components such as engine, transmission, and suspension, contributing significantly to the car stiffness. It determines the length of the vehicle and to a great extent its final shape. The under-body structure can be designed in either integral or modular form.

2.1. Integral design of the under-body structure

An under-body structure with integral design architecture is generally characterized by high complexity. This means that if a change is made to a part of the under-body, it will affect other surrounding under-body parts too. Most of the times, such changes require a redesign effort by the designers and production planners. The integral under-body (Fig. 2) due to its inflexible architecture is not keen in deriving alternative design variants. Therefore, only a single variant is considered to be produced by an assembly line configuration.

2.2. Modular design of the under-body structure

Modular design of the under-body structure may consist of three main modules: the floor, the front end and rear end modules (Fig. 2). Through this modularity, alternative design variants may be generated by mixing and matching the different variants of each module. Furthermore, through the split-up of the modules, scalability in the longitudinal dimension of the under-body structure can be easily achieved, since only a small portion of the under-body parts will be influenced and will require redesigning. Based on this scalability feature three alternative design variants of the under-body structure can be generated (Fig. 3). A modular under-body is considered as a platform segment from which alternative BiW variants in terms of shape and dimensions can be produced [8].

3. Assembly systems configurations

We assume a generic vehicle demand profile (Fig. 4) for a period of two years. A high peak appears after production launch, while a slowdown of demand due to market competition may follow.

A marketing campaign, at the end of the first year, can create a second lower peak, before the end of the production phase. After the second peak an overlap with the next generation of product may appear. The total production volume for two years is 1,200,000 vehicles, and is distributed over seven vehicle models (Fig. 5). Coupe,

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0007-8506/$ – see front matter © 2011 CIRP.
doi:10.1016/j.cirp.2011.03.009

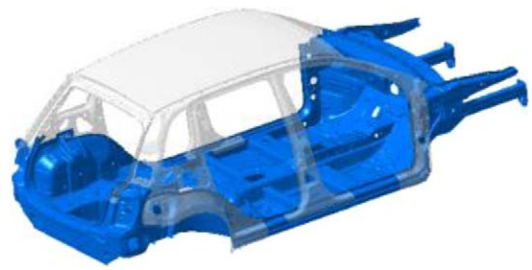

Fig. 1. BiW and the under-body structure (integral design).

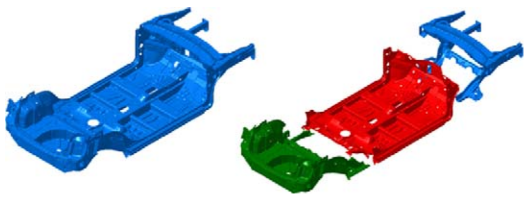

Fig. 2. Integral under-body (left) and modular under-body (right) structures.

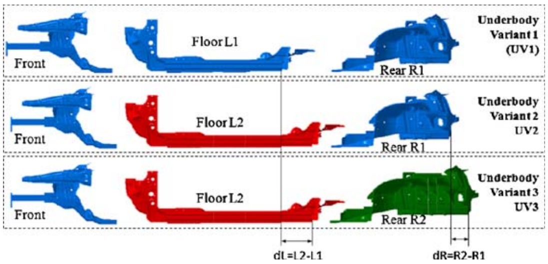

Fig. 3. Modular under body structure variants different lengths within floor (dL) and rear end (dR).

cabriole and three doors hatchback vehicles models are produced from underbody variant 1 (UV1). Five doors hatchback and four doors sedan vehicles models are produced from underbody variant 2 (UV2). Station wagon and five doors mini-van vehicles models are produced from underbody variant 3 (UV3).

Production volume distribution per vehicle variant is based on current European automotive industry trends [9]. In general the demand for sport/high performance vehicle variants is lower than the demand for family/large space/utility vehicle variants.

3.1. Assembly system for the integral design

The assembly system configuration and decomposition for the integral design of the under-body structure is based on the following assembly configuration (Fig. 6):

- *Sub-Cell#1 (s1):* Front structure assembly sub-cell: front side rails, side cross members and dash panel.
- *Sub-Cell#2 (s2):* Main Floor assembly sub-cell: front and rear cross members, floor side panels, tunnel.

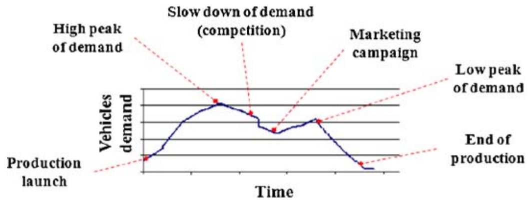

Fig. 4. Vehicles demand profile for a period of two years.

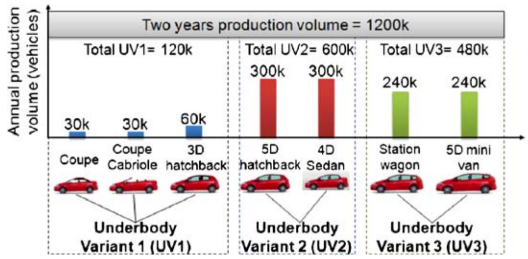

Fig. 5. Under-body structures variants and two years production volume.

- *Sub-Cell#3 (s3):* Rear frame assembly sub-cell: back panel, rail member and side rails.
- *Main-Cell#1 (1):* Front structure, floor reinforcement's assembly and main floor assembly.
- *Main-Cell#2 (2):* Output of Main-Cell#1, rear frame assembly.
- *Main-Cell#3 (3):* A-pillars, sills, spare wheel well, hill-kick, rear panel and re-spotting of Main-Cell#2 output.

For the assembly of the three under-body structure variants for the integral product design, three independent lines are required for the production of the three under-body variants.

3.2. Assembly system for the modular product design

The assembly system configuration and decomposition for the modular design of the under-body structure is based on the following assembly configuration (Fig. 7):

- *Sub-Cell#1 (s1):* Front module assembly and re-spot sub-cell.
- *Sub-Cell#2 (s2):* Floor module assembly and re-spot sub-cell.
- *Sub-Cell#3 (s3):* Rear module assembly and re-spot sub-cell.
- *Main-Cell#1 (1):* Front and floor modules assembly.
- *Main-Cell#2 (2):* Output from Main-Cell#1, rear module and re-spotting.

For the production of the three modular under-body structure variants one assembly line may be required since all variations of the modular design can be assembled by one line.

3.3. Differences of the two assembly configurations

Several benefits and challenges are to be considered about the two different assembly systems for the integral and the modular under-body structure. The assembly line for the modular design can produce

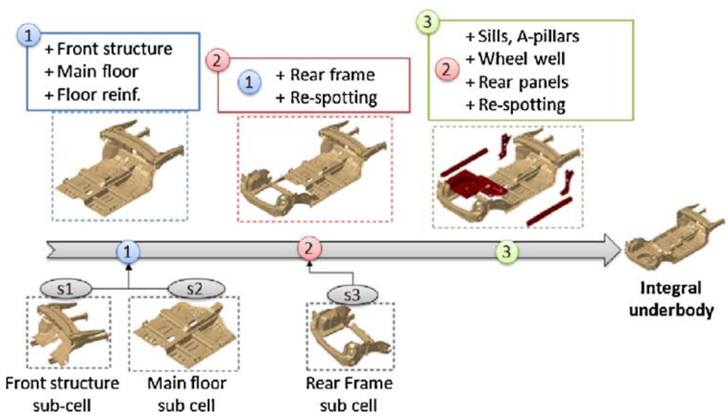

Fig. 6. Integral under-body assembly configuration.