

Virtual Vehicle Design based on Key Performance Indicators Assessing the Vehicle Portfolio

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ABSTRACT

This paper focuses on the manufacturer's conflict in the conceptual design of commercial vehicles between highly customized special vehicles and the greatest possible degree of standardization. Modularity and standardization are crucial success factors for realizing high variance at the best cost efficiency in development and production as well for achieving the highest quality standards at reduced efforts for technical validation. The presented virtual design approach for commercial vehicle concepts allows for purposeful design and integration of new concepts and technologies on the component level in an existing product portfolio - not neglecting manufacture's portfolio requirements concerning standardization and modularity. The integrated tool chain helps to bring trade-offs to a head that exist in balancing between dedicated vehicles with best customer-relevant characteristics and standardized vehicles with the highest degree of commonality. For this, one core aspect is KPI-based portfolio assessment which is presented in the focus of this paper. The embedding in an integrated tool chain, its setting and functionality are outlined in overview.

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INTRODUCTION

With products more and more diverse and growing vehicle portfolios on the market, variant management has become of enormous significance in coping with challenging cost and quality requirements. Modular systems and related methodologies are a common approach in many companies and currently are widely discussed in research. But the research on modularity and its management has not yet reached application-oriented maturity, and implementation in industry is rather fragmentary for different companies, industries and products.

The focus of this paper is the conceptual design of commercial vehicles which are high-variant products with comparatively small production volumes [1]. Therefore a concept development phase focusing on variance becomes a major aspect in planning and determining standards, modularity and commonality within the future product portfolio. Due to long product lifecycles (typically 20 to 30 years), the basic architectures of commercial vehicles continuously undergo a

small evolution and many technical changes and innovations have to be held available - in many cases triggered by changes in legislation. Therefore, both the careful planning of design interfaces and their management are important for successful use of modularity and commonality within the product range.

This paper regards virtual concept design and portfolio assessment at MAN Truck & Bus AG (short: MAN), one of the major German manufacturers of commercial vehicles (trucks, buses, chassis and components). With comparatively low production volumes of approximately 100,000 vehicles per year and a large portfolio of configurable vehicles (about 1046 possibilities from a functional point of view), the vehicle design should be highly modular to cater to the breadth of the product portfolio with the existing R&D resources. In particular, the advantages of modularity in this industry are found in focusing design efforts on commonality (i.e. designing once, using multiple times) rather than in the economies of scale in production and purchasing, which are still low due to overall low production volumes. In addition to advantages in cost efficiency, quality can also be improved: Close document

use of standardized components and modules allows for more economical technical validation and facilitates concentration on a minimum of reference vehicles for testing.

Research Methodology

The research presented is conducted in the context of a multiyear application-oriented and industry-relevant research project in cooperation of MAN Truck & Bus AG and Technische Universität München. It is based on work at the company that is protocolled and reviewed continuously with specialist departments of MAN as well as with outside experts from academia and consulting. In this way, an accurate, neutral reflection of the research results is assured, and the implementation process at the company is promoted sustainably. The identification of best practices and scientific principles was aided by student theses combining industrial and scientific approaches and practices. The research methodology is reviewed and validated by meaningful industry-relevant use cases. All results were discussed in depth within the company's architecture group and with senior management in a series of meetings and workshops.

Background and Context at MAN

The primary niche occupied by MAN is that of mass customization for specialized markets. To facilitate this, vehicles are built on a highly modular architecture that supports a wide range of applications (trucks for different uses such as logging, garbage disposal, military, etc.), market segments (e.g. long-haul, distribution, traction) and worldwide markets (Western Europe, Middle East, South America, etc.). In a build-to-order process, truck variants are configured from a mostly pre-documented set of components. Currently, variant management (i.e., documenting components and their configurability into overall vehicles) is executed mostly ex-post by the departments responsible for the bill of material. The bill of material itself is a complex host-based IT system that manages approximately 100,000 different parts and their relationships. Over the past four years, a more targeted product architecture planning process (as part of the concept design phase) was introduced, with the goal of developing and documenting only those parts that are needed from a customer's point of view [2]. To this end, new processes were introduced, namely a specification phase to generate a set of product specifications in a formal manner, a product architecture phase to translate the functional specifications into a consistent vehicle architecture, and a package planning process to ensure that the product architecture is clash-free for the intended variants. All of these processes had to be embedded into the existing environment taking into account all legacy processes and existing boundary conditions. This paper reviews briefly the current state of implementation at MAN (multi-level modular kit development) and further development approaching procedural implementation at the company and picks up latest research approaches in architectural vehicle design from a multi-year research project.

Problem Description

In their capacity as business-to-business investment goods, commercial vehicles are characterized first and foremost by challenging requirements concerning manufacturing costs and durability, i.e. quality issues. Against this background, manufacturers strive to combine improvements in cost efficiency and quality by means of implementing modularity and internal standardisation in their development processes - coping with the market-related constraint of a required high variant product portfolio.

In the first instance, the engineering design process is affected by four challenging aspects that complicate modularity and standardization objectives [3]:

- The variant spectrum for commercial vehicles is comparatively high and results both from an OEM's (original equipment manufacturer) strategic alignment and from an unavoidable high variety of customers' utilization scenarios and transportation tasks. Typically vehicles are assembled to order, yet the design caters to a high degree of specialization in transporting specific goods.
- The positioning and the available installation space for components are essential aspects. Customers' orders typically include several customization requests profoundly influencing the vehicle layout and asking for individual installation space for own components (e.g. tool boxes).
- Further adaptations are done by body manufactures to finalize the vehicle beyond the OEM's area of influence (such as tippers, mixer trucks, etc.). To allow for optimal body mounting, the OEM has to make many interfaces available as optional adaptations. If modifications cannot be done simply and cost-efficiently, vehicles are deemed to be body-unfriendly and show competitive disadvantages.
- All aforementioned aspects appear in combination with long life cycle periods of 20 - 30 years, bringing substantial uncertainties regarding future changes - initiated on customer side or technologically or due to legislation.

These challenges result in high efforts to engineer and manage this variance with an unavoidable lack of transparency [4]. With respect to the low sales volumes per vehicle variant, commercial vehicle portfolios are not upgraded or set up newly all at once, but evolve slowly over many decades. Thus, the modular kit is growing additively with little systematic forward planning. New customer demands and vehicle configurations are made possible - corresponding to the customer order inflow. The component variants and especially their dependencies increase steadily, and as a result, changes evoke further subsequent changes. Efforts, costs and even the exact portfolio penetration of changes can be hardly estimated. Hence, at MAN a significant percentage of productivity in engineering and construction is necessarily dedicated to a particular variance context before realizing product changes.

On account of these challenges, in a current effort the architecture design phase at MAN is strengthened to support a more consistent frontloading in engineering [2, 3]. In order to further this sustainably, adapted design tools are created for the early architecture phase. They support the development of architectural standards taking into consideration the tolerable boundaries of complete vehicle characteristics as well as collision-free component integration. Accordingly, in the early phase they cope with low detailed engineering information.

As the manufacturer tries to avoid an accumulation of several - even if perfectly customized - unique vehicles without any synergies, but strives for the highest possible commonality within the whole vehicle portfolio, the success and consequences of standardization activities on the portfolio have to be systematically investigated and measured. On the level of conceptual vehicle design, this can be performed by a portfolio assessment methodology presented in the focus of this paper. It is embedded in a virtual vehicle design tool chain which is outlined in overview.

Structure of this Paper

First, some basic background about the object and methodology of research is given and a broader understanding of the issue is created in the introduction.

Then the early concept phase of commercial vehicle design is reviewed with the focus on the state of the art procedural implementation at MAN and an overview on the virtual vehicle design tool chain in the context of this research.

The chapter Portfolio assessment constitutes the principal focus of the research in this paper: The state of the art and objectives are discussed in detail, followed by an in-depth description of the methodical approach and finally two meaningful application cases are presented.

Finally, a summary and conclusion of this study are provided.

EARLY CONCEPT PHASE AND VIRTUAL VEHICLE DESIGN - STATE OF THE ART

Initially, the state of the art is provided - focussing on the relevant aspect that is underlying in the context of this research for the actual key issue in this paper: Portfolio assessment for optimal cost efficiency within the modular kit (see next chapter).

For an overview, the procedural implementation of the early concept phase and related approaches at MAN are outlined (more discussed in greater detail in [3, 5]). These form the starting point for the architecture design tool chain which will be presented (discussed in detail in [6]). The brief description

of the tool chain in turn leads over to the portfolio assessment methodology that is embedded therein.

Architecture and Multilevel Modular Kits

The current modular kit development at MAN is represented at two levels: complete vehicle ("Modular Kit Truck") and modular design at component level ("Technical Kits"). It utilizes three different structures (see [Figure 1](#)):

- "Yellow Structure"
This contains the variant properties ("codes" or "properties"), combination and selection rules, applied by a customer when configuring his truck.
- "Blue Structure"
This embodies the physical component level, describing all the assemblies and parts of a truck.
- "Green Structure"
This provides a hierarchical generic product decomposition: Main component groups ("KHG") to component groups ("KG") to sub component groups ("UKG") and components ("K"). At its lowermost level, the "component variants" (black bins) collect the relevant parts and assemblies and by assigning the entities of the "Yellow Structure", their validity in a vehicle is described.

The modular kit at vehicle level is based on a centralized product decomposition ("Green Structure") and constitutes a logic level for administration and the management of the overall design process. Its basic principles are depicted in [Figure 2](#): The vehicle properties (on the left, "yellow structure") are linked to available technical variants (i.e. component variants of the "green structure", on the right) in the context of a customer order. When specifying a vehicle in MAN's sales configurators with codes (referred-to properties), gradually only the adequate component variants remain valid while others are rejected. Having selected all relevant properties (wheel base, total weight, engine power, type of cabin etc.) only exactly one component variant per generic component is chosen: Then the configuration process is explicit and successful. The modular kit at the vehicle level is characterized by identical component variants allowing for cross-product application as independently and comprehensively as possible. Challenging requirements for component variants concerning interfaces and architectural standards are derived therefrom.

In order to achieve all required vehicle properties ("Yellow Structure") multiple variants per component class are typically needed in the portfolio (e.g. axle variants due to different axle loads, see [Figure 1](#)). This is where the modular kits at the design level ("blue structure") start: Their main objective is to strive for high commonality to save costs and effort by reducing inner variance - although needing multiple variants due to variant drivers (such as brake system and tonnage for axles).

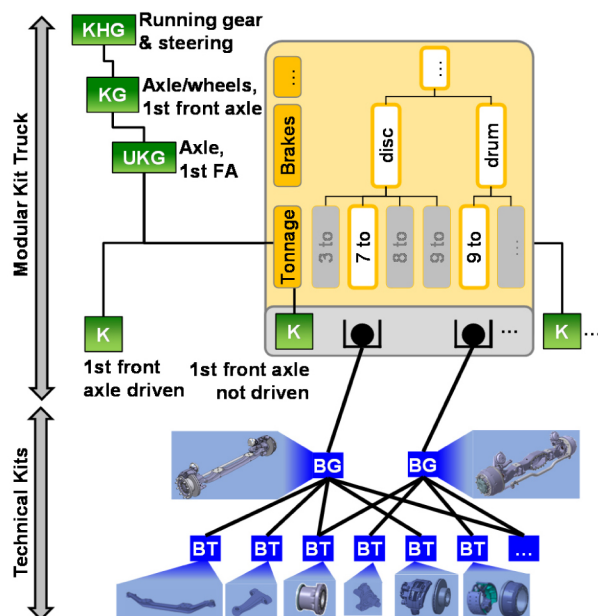


Figure 1. Three structures describing modular kits at MAN (illustrative example)

Given that these variant drivers do not affect the overall component but only certain specific parts and sub-assemblies, it is possible for component variants to share a high

percentage of common parts - if designed systematically and target-oriented. In the exemplary case of Figure 1, different axles are needed due to different braking systems and tonnage classes. But within the modular kit axle, these axles can be configured of standardized building blocks applying a high percentage of common parts.

The responsibility for the modular kits at the design level is assumed directly by the technical departments.

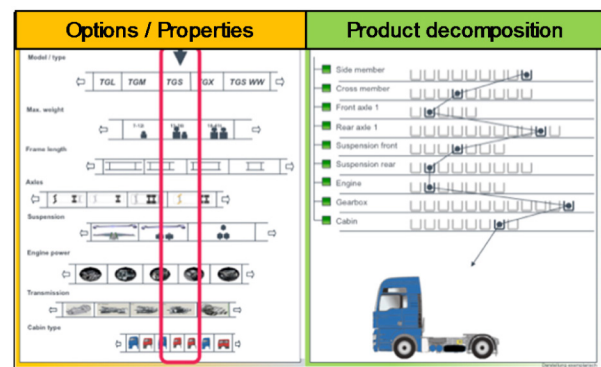


Figure 2. Modular Kit vehicle level [VDI, TMCE]

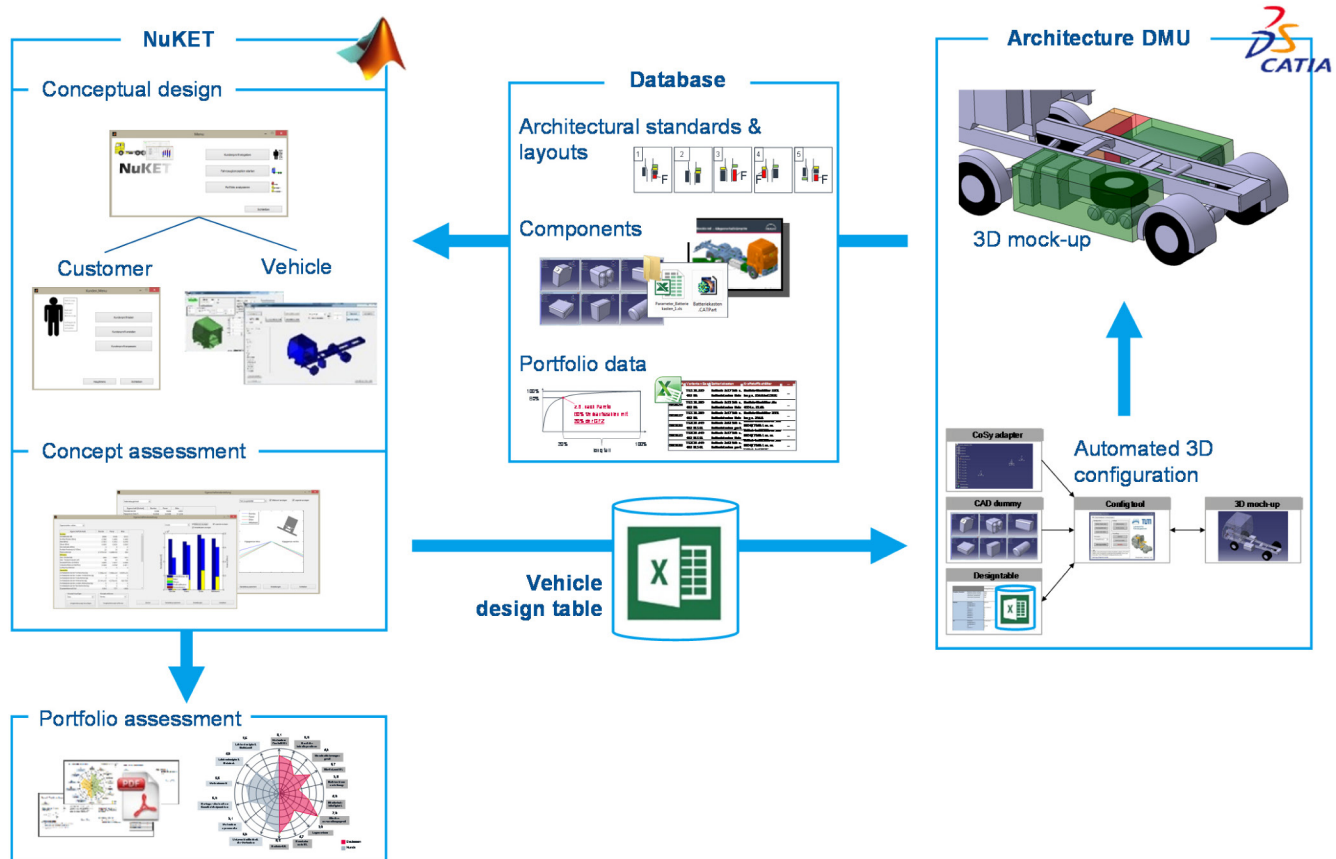


Figure 3. Integrated tool chain for conceptual vehicle design and assessment of vehicle concepts and resulting vehicle portfolios: NuKET (German: NutzfahrzeugKonzeptEntwicklungsTool = Commercial vehicle concept design tool) interacting with an automated Architecture digital mock-up (Architecture DMU)

Virtual Vehicle Design in the Early Concept Phase

The following virtual tool chain for commercial vehicle concept and portfolio design constitutes the embedding environment for the portfolio assessment methodology focused on in this paper (see next chapter). For this reason, it is briefly outlined to put its concept across. A more in depth description including use cases and a detailed discussion of its performance for vehicle designing and layouting is provided in [6].

To meet the design challenges mentioned in the introduction for commercial vehicles in the early concept phase, a design methodology for particular concepts and whole vehicle portfolios was developed and concentrated in the implementation of an integrated tool chain (see Figure 3). The particular building blocks are outlined below.

Tool Concept

In the center of the methodology presented, an integrated virtual tool chain is established. It includes a mathematical design tool for vehicle concepts and associated customer profiles and operational scenarios, respectively (implemented in MATLAB, see Figure 3 left). After linking vehicle concept and usage profile, essentially complete vehicle performance factors are calculated and referred to a customer-specific rating system (relevance and utility value of criteria). In the event of several vehicle concepts, there is a KPI analysis assessing the whole vehicle portfolio (see next chapter, Figure 3 lower left). Finally every vehicle concept (stored in a vehicle design table, Figure 3 lower center) is converted automatically into an architecture digital mock-up (see Figure 3 right). In the Architecture DMU component integration, possible collision and potential standard packaging spaces and vehicle layouts are investigated. Promising standardized layouts (to be published in [7]) can then be set as compulsory for all subsequent vehicle concepts to be designed in NuKET (closed-loop portfolio development) to enforce commonality and synergetic effects in development and production.

NuKET

The design tool *NuKET* allows for developing vehicle concepts through accessing a data base of 30 actual main components (e.g. fuel tank, cabin) with several corresponding component variants (e.g. 66 geometrical variants of fuel tanks, i.e. different material, length and cross-section). Every component variant is represented by a conceptual abstracted geometry and relevant characteristics (e.g. mass, CG, material, package requirements, cost data etc.). For visualization and collision detection, CAD geometry is integrated (see Figure 4).

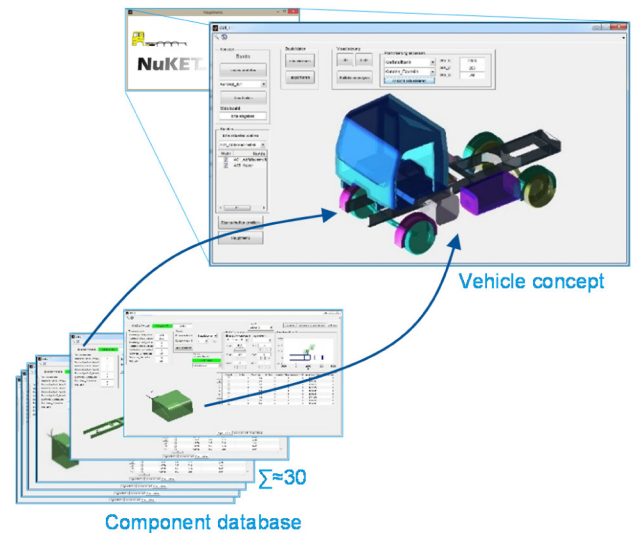


Figure 4. Development of vehicle concept based on abstracted component geometry and basic characteristics

To gradually develop complete coherent vehicle concepts, main components can be manipulated as to their position (e.g. change of ladder frame side) and their specific variant (e.g. 550l replaces 400l fuel tank). If required for challenging complete vehicle characteristics, design studies on the component level can also be conducted by adding new component variance with individual properties. One or several customer profiles can be assigned to every vehicle concept in order to analyze their degree of applicability (see Figure 5).

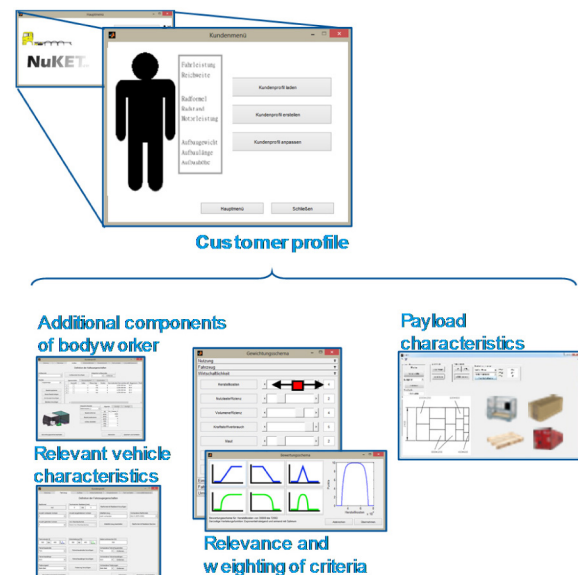


Figure 5. Defining customer profile and operational scenarios

Customer profiles define desired vehicle characteristics (e.g. payload, TCO, emissions, axle loads, ramp angles etc.), usage and payload characteristics (standard loading equipment, load balancing, tonnage, road class split etc.). For a final assessment, customer-specific criteria weightings and evaluation parameters can be saved.