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DERIVATION, ANALYSIS AND COMPARISON OF GEOMETRIC REQUIREMENTS FOR VARIOUS VEHICLE DRIVETRAINS USING DIMENSIONAL CHAINS

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Abstract

Following the development of new drivetrain concepts (e.g. BEV and FCEV) the comparison of drivetrains becomes increasingly important during the vehicle architecture design. Thereby, the geometrical requirements of the drivetrain architectures, respectively the minimal required distances between components, maximal component sizes as well as cross-vehicle dimensions, are often unknown at the beginning of the development. This is predominantly caused by the multitude of requirements and the high variance of components. Thus, as a starting point of a new development, experts are required to manually determine and compare the geometric requirements from existing vehicles. To increase the efficiency, a methodology is developed which derives, analyses and compares the minimal required distances, the maximal component sizes as well as the cross-vehicle dimensions of drivetrain architectures, by using dimensional chains of series vehicles. Thereby, the most relevant load paths and vehicle configurations are identified, hence reducing the complexity. Using the new methodology, it is possible to derive geometric requirements and to compare drivetrain architectures in an efficient way.

Keywords: New product development, Design methods, Complexity, Vehicle package, Dimensional chains

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1 INTRODUCTION

1.1 Background Description

Depending on the organizational structure of an automotive manufacturer the vehicle concept development department is responsible for the following three stages: the development of modular vehicle systems, vehicle platforms and vehicle derivates. Starting the development with the modular vehicle system the drivetrain and vehicle architecture is defined for multiple vehicles of different vehicle segments. Thereby the positions of various components (e.g. engine, gearbox) are standardized for all vehicles. Based on the modular vehicle system several vehicle platforms are created for vehicles of the same segments, increasing the number of standardized component positions steadily. Coming from the vehicle platform the packages of all derivates are subsequently arranged by positioning all parts.

During all three stages of the vehicle concept development there is always a development from the outside to the inside and from the inside to the outside. Coming from the outside the vehicle dimension concept defines the overall dimensions such as the overhang, wheelbase and width and thereby specifies the overall available installation space. This process is mainly driven by the vehicle design, the previous model and competing models. In contrast thereto, the components are positioned during the vehicle architecture design, defining the necessary installation space and thus the exterior dimensions from the inside to the outside. Hereby the dimensions of the components and the distances between them are designed to fulfil legal and consumer requirements. In the end, there must be a convergence between the two design approaches.

Following the vehicle architecture design, current vehicles are mainly designed with combustion or hybrid drivetrains. For long-term sustainability, it is inevitable to also integrate electric drivetrains in the vehicle. This can be done by integrating several drivetrains in one common vehicle platform or by a complete change of the drivetrain, e.g. from combustion to electric engines. For both scenarios, the geometric requirements of the drivetrains have to be known.

1.2 Problem Description

At the beginning of the vehicle architecture design of a new vehicle, information about general requirements from legal framework, consumer protection and customer-needs is mostly available. However, it is uncertain, how these requirements can be translated into geometric requirements, respectively minimal required distances between components, maximal component dimensions and cross-vehicle dimensions, such as the crash length. However, those dimensions are required for the design and comparison of the drivetrain- and vehicle architecture.

The minimal required distances between components are necessary to comply with general requirements, like pedestrian protection. However, exact values for the fulfilment are not available at the beginning of the development, due to a multitude of different, country-specific general requirements.

Maximal component dimensions are determined by general requirements, such as the demanded engine power. Due to the high number of components and component variants (e.g. ten engines with different engine power) the dimensions and the geometric differences between variants are often uncertain.

Cross-vehicle dimensions, for example the crash length, are relevant to comply with comprehensive general requirements, such as the deceleration during high speed crash. Due to the high number of requirements and testing procedures, target values are hard to predict. In addition, cross-vehicle dimensions depend on the component variants and therefore the vehicle configuration. However, the most critical vehicle configurations and design paths, for which compliance with the requirements is most difficult, are often unknown. Consequently, all vehicle configurations and design paths must be considered.

The uncertainties regarding the distances are increased by the dependency of the dimensions on vehicle parameters, such as the vehicle weight, which are as well difficult to predict at an early design stage.

Furthermore, the information about the geometric requirements, respectively the dimensions, is not only needed for one drivetrain architecture. For selection or change of the drivetrain architecture as well as for the integration of several drivetrains in one vehicle platform, a comparison is necessary. Otherwise, the differences between drivetrains regarding the geometric requirements and the effects of changes are unknown.

To overcome these uncertainties at the beginning of the vehicle architecture design, the relevant dimensions can be measured from existing series vehicles. As a starting point this data can be used for the analysis of geometric requirements and for the comparison of drivetrain- and vehicle architectures (Figure 1).

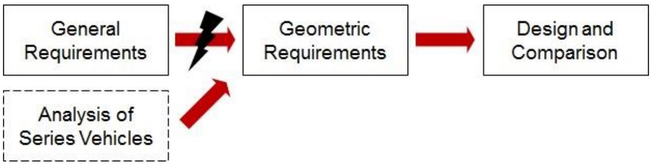

Figure 1. Approach for the analysis and comparison of drivetrain- and vehicle architectures at an early stage of the vehicle architecture design

Up to now it is primarily the time-consuming task of experts to manually examine and compare the minimal required distances between components, the maximal component dimensions as well as cross-vehicle dimensions, by utilizing data measured from previous and competitor models.
In order to increase the efficiency during the vehicle architecture design, a methodology and software tool was developed for the automated geometrical analysis and comparison of drivetrain- and vehicle architectures. Thereby dimensional chains, which add up by distances between adjacent components and component dimensions, are used as a basis. These are measured from CAD data of series vehicles and stored in a database. Subsequently, minimal required distances, maximal component dimensions as well as cross-vehicle dimensions, representing the geometric requirements, are calculated and compared. Furthermore, critical design paths and vehicle configurations are identified out of numerous possibilities. Taking account of the high number of dimensions and variants, a MALTAB algorithm is used for the computation and comparison. Results are then visualized in a parametric CAD model.

2 STATE OF THE ART

2.1 Existing Approaches to Vehicle Concept Development

State-of-the-art vehicle concept development should be distinguished between the outside to inside, the vehicle dimension concept, and the inside to outside, the vehicle architecture design.
In the vehicle dimension concept, the use of dimensional chains is widespread. The main exterior and interior dimensions of motor vehicles are defined and standardised through SAE J1100 (2001). The definition contains length dimensions (Figure 2) such as the front and back overhang (L104/L105) as well as the wheelbase (L101), adding up to the vehicle length (L103). Similar dimensional chains can be found in the width and the height.

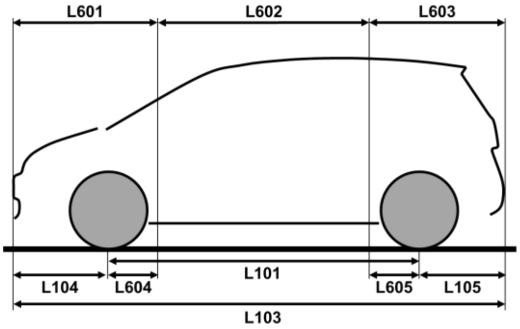

Figure 2. Dimensional chains of the vehicle dimension concept (based on Kuchenbuch, 2012)

Based on the dimensional chains, standardized in the SAE J1100, Raabe (2013) builds up a parametrical model for the fast creation of consistent vehicle dimension concept. Tzivanopoulos et al (2014) uses neural networks to find the best vehicle dimension concept for various vehicles (e.g. BEV) and scenarios (e.g. autonomous driving), focusing on the passengers seating position. As the drivetrain and the vehicle package is not considered within the vehicle dimension concept, less component variants and therefore dimension have to be considered, thus reducing the complexity.

On the contrary no method has been found using dimensional chains holistically during the vehicle architecture design. Instead parametrical package models (Hirz *et al.*, 2008) and package optimizations (Kuchenbuch, 2012; Matz, 2015) are used. These tools aim at the creation of new solutions and packages. With many degrees of freedom for the positioning of components, they are focusing on large scale changes. Consequently, these tools are not supporting the analysis of geometric requirements and the geometric comparison of existing drivetrain- and vehicle architectures.

2.2 Research gap

Based on the problems regarding the vehicle architecture design and the state-of-the-art, several research issues have been identified. The main question is how dimensional chains can be used to analyse and compare the geometric requirements and dimensions of drivetrain- and vehicle architectures, to enable the beginning of the development. Therefore, one challenge is the identification of dimensional chains for all possible drivetrain architectures. Another question concerns the determination of cross-vehicle dimensions, maximal component dimensions and minimal required distances, for the derivation of geometric requirements. Lastly, there is the question of the automatized comparison and visualization of the results.

3 METHODOLOGY FOR THE DERIVATION AND COMPARISON OF GEOMETRIC REQUIREMENTS

In an attempt to close the research gap a methodology is developed to derive, analyse, compare and visualize the distances, component dimensions as well as cross-vehicle dimensions of various drivetrain architectures by using dimensional chains. This approach will be exemplified considering the front of a vehicle with a front-mounted engine. However, a transfer of the methodology to the entire vehicle is certainly possible.

Before an overview of the methodology is given dimensional chains, within the vehicle architecture design, will be referred to in detail.

3.1 Definition of Dimensional Chains

Dimensional chains add up by the distances between adjacent components and the dimensions of the components along a defined coordinate direction. As an example, a dimensional chain in x-direction is shown in Figure 3.

This dimensional chain adds up by eleven single dimensions: the thickness of the license plate and the bumper (1), the distance between the bumper and the bumper beam (2), the thickness of the bumper beam (3), the distance between the bumper beam and the radiator (4), the thickness of the radiator (5), the distance between the radiator and the engine (6), the length of the engine (7), the distance between the engine and the front wall (8), the thickness of the front wall (9), the distance between the front wall and the pedal (10) as well as the length of the pedal (11).

The selection of starting and ending points (e.g. foremost point and ball of foot), as well considered by the dimensional chains of the vehicle dimension concept, makes a comparison with the exterior dimensions of the vehicle possible (e.g. L601 in Figure 2).

All dimensions referred to in Figure 3 can be recorded in 2D-sections along predefined positions (e.g. xz-section at y=0). However, such an approach would lead to results of only limited validity, since the smallest distance, respectively the constriction between two components will rarely be found along a single section due to the complexity of the component shapes.

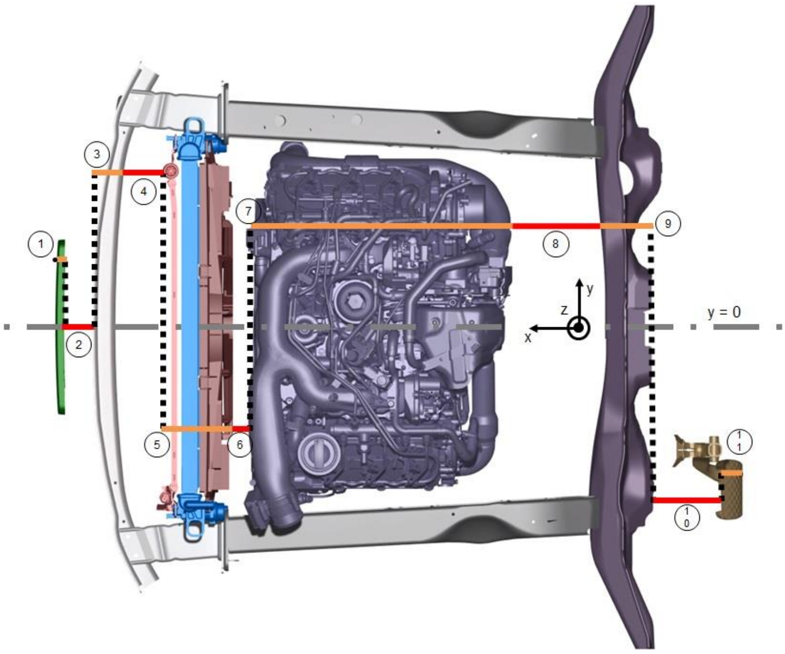

Figure 3. Overview of a dimensional chain in x-direction

For that reason, the distances between adjacent components (without deformable elements as e.g. brackets, hoses and wires) are measured from the 3D-CAD-Models of vehicles along the x-, y- or z-coordinate direction. If measuring along any direction the distance between the components can be even smaller (Figure 4). However, these measures are neglected, as they do not add up to dimensional chains.

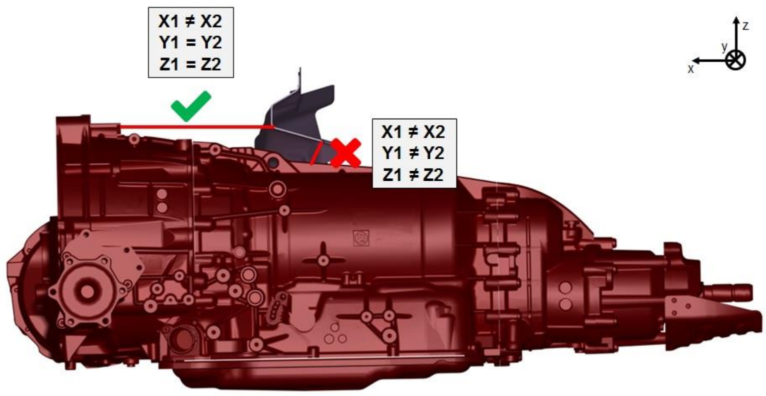

Figure 4. Measuring of distances between the gearbox and the front wall along the x-coordinate direction

The dimensions of the components are determined between the two surrounding distance measurements. For example, the length of the engine ((7) in Figure 3) is calculated from the last coordinate value of the previous distance measure ((6) in Figure 3) to the first coordinate value of the succeeding distance measure ((8) in Figure 3). With this approach, the dimensions of the components, within the dimensional chains, are considered.
Consequently, it is possible to identify and measure dimensions and dimensional chains in all three coordinate directions and for all drivetrain architectures. Furthermore, there can be several dimensional chains per direction. In addition, one dimensional chain can be split up and have several design paths (e.g. engine to front wall or engine to catalytic converter to front wall). But as the different design paths add up mostly by same dimensions they are not regarded as a separate dimensional chain.
Due to different component variants, it must be considered that each distance and component dimension of a dimensional chain can have multiple characteristics and values. For example, the dimension between the radiator and the engine can be characterized by multiple values, due to different radiators for various countries and multiple engines.

3.2 Overview of the Methodology

The methodology can be divided into five steps (Figure 5), which will be described in the following. At first the dimensional chains have to be identified. Therefore, different drivetrain architectures (ICEV, BEV, FCEV) and the components which are the most relevant ones for the vehicle architecture have to be considered. In the second step, all individual dimensions of the dimensional chains have to be recorded from available CAD-models of series vehicles, using a CATIA macro. Due to the high variance of the components each dimension can possess multiple characteristics. Thirdly, the recorded dimensions are saved in a SQLite database. The metadata of the dimensions e.g. the contemplated component variants and properties must be documented in the database likewise. Within the fourth step, the minimal required distances and the maximal component dimensions can be determined out of the variety of characteristics, based on the database using MATLAB. In addition, the individual dimensions are added up to dimensional chains. However, not all component variants can be combined with each other. Hence a MATLAB algorithm is utilized, which builds up all possible vehicle configurations, like a variant tree, based on the metadata of the dimensions. For all possible vehicle configurations, cross-vehicle dimensions as well as critical design paths and vehicle configurations can be calculated and identified. The results can be used to predict the geometric requirements and to compare drivetrain- and vehicle architectures as a starting point of a new development. During the fifth step the output is visualized in a parametric dimensional chain model.

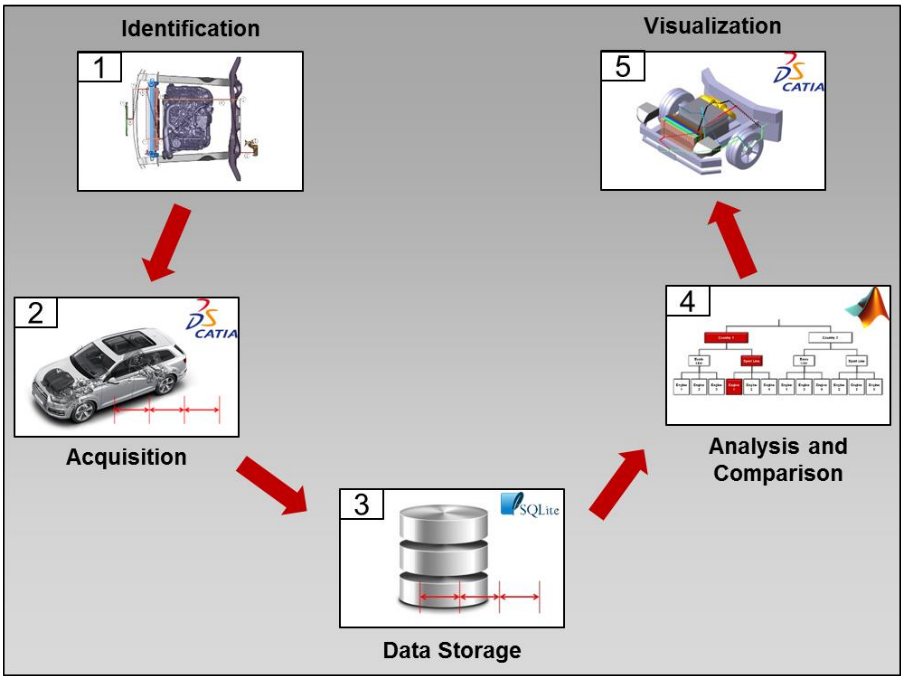

Figure 5. Overview of the five steps of the methodology

3.3 Identification of Dimensional Chains

As mentioned in section 3.1 dimensional chains add up by the distances between adjacent components and the dimensions of the components. To ensure the comparability between the drivetrains architectures standardized dimensional chains have to be identified.

Therefore, the methodology only considers components which are relevant during the vehicle architecture design. The relevance is assessed by the impact on the functionality of the drivetrain, the effects in case of high speed crash as well as the number of possible mounting positions. Components with a high amount of mounting positions are regarded as insignificant, since they can be positioned more freely at a later stage of the vehicle concept development.

Consequently, an analysis of the number of mounting positions was conducted using the CAD-Data of ten series vehicles from five automotive manufacturers with six different drivetrain architectures (e.g. front and rear wheel drive, combustion, hybrid and electric engines, longitudinal or transverse installation). For the identification of the different mounting positions the front of the vehicle was divided in 18 sectors (Figure 6). Based on the results, the engine has only two mounting positions (Figure

6). Therefore, this component is considered as very important. The engine control unit, on the contrary, can be positioned at one of six positions. Hence the control unit will be categorized as less important and not considered during the identification of the dimensional chains.

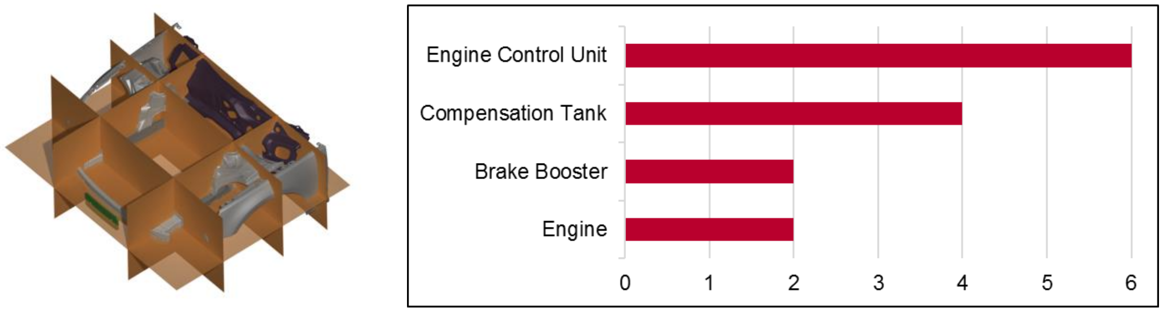

Figure 6. Vehicle sector model and number of mounting positions of four components

With the smaller number of components to be considered, the dimensional chains can be derived in the x-, y- and z-coordinate direction. After the identification, a total of five dimensional chains (Figure 10) and 56 design paths can be counted for the vehicle front, which add up by 50 distance dimensions and 28 component dimensions. Most of the dimensional chains and design paths apply for all drivetrain architectures. For example, the dimensional chain shown in Figure 3 is valid for both combustion and electric engines. Because of the differences between the drivetrain architectures it can be nevertheless necessary to define design paths for specific architectures. As an example, an ICEV requires an additional design path from the engine over the catalytic converter (Figure 7). An FCEV requires a supplementary design path over the fuel cell. Nevertheless, an evaluation depicted that approximately 60 % of the defined dimensions are consistent for all drivetrain architectures, which allow a considerably precise comparison of the architectures.

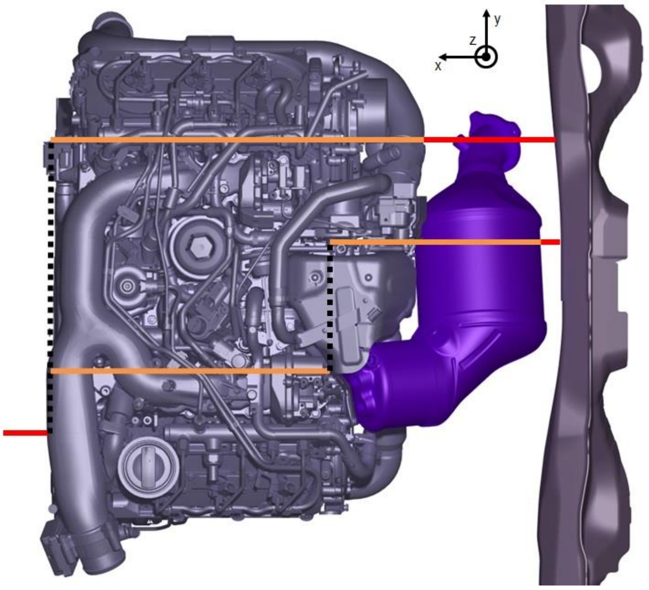

Figure 7. Overview of different design paths

3.4 Acquisition of Dimensional Chains

For the standardized dimensional chains, a CATIA macro in the DMU (Digital-Mock-Up) Space Analysis is utilized, determining all distance dimensions of the respective 3D-vehicle-model with all vehicle configurations. Due to the high variance of the components each dimension can possess multiple characteristics and values. The dimensions of the components are subsequently calculated between the two surrounding distance dimensions for all eligible combinations of the distance characteristics.

3.5 Storage of Dimensional Chains

For the purpose of storing the dimensions a SQLite database with a MATLAB user interface is set up. In this database, all captured dimensions can be saved. For one vehicle over 600 dimensions have to be stored to represent all dimensions. Thereby it is important, that the metadata, respectively the contemplated component variants and properties, of the dimension are as well documented in the database.

3.6 Analysis and Comparison of Dimensional Chains

The database contains a large number of dimensions with multiple characteristics. For individual dimensions, the minimal or maximal characteristics, depending whether from distances or components, are analysed and compared using MATLAB. Thereby it is distinguished between, for example engine variants, so that effects of different variants can be visualized (Figure 9).
For the analysis of the cross-vehicle dimensions and the corresponding design paths and vehicle configurations, the individual dimensions must be added up to dimensional chains. Thereby, it must be guaranteed, that only dimensions belonging to the same vehicle configuration are aggregated. It is not possible to simply pick the minimal or maximal characteristics of each dimension, since these do not necessarily belong to the same vehicle configuration.
Thus, an algorithm is programmed in MATLAB, which builds up the possible vehicle configurations, similar to a variant tree (Figure 8). This combination is executed with the metadata, e.g. the component variants, of the dimensions. Hence it can be ensured that only dimensions from the same configuration are added up.

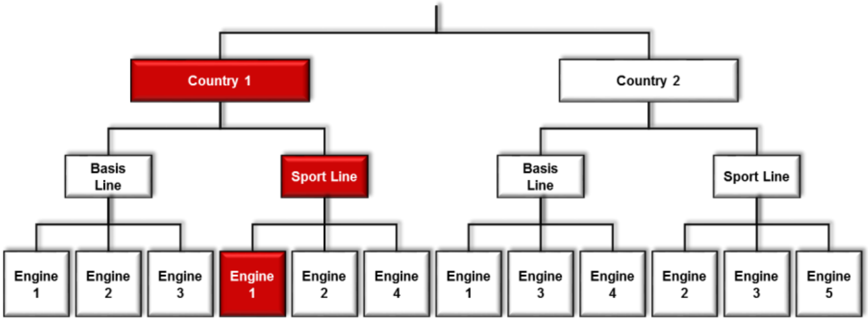

Figure 8. Excerpt of a variant tree with critical vehicle configurations

Subsequently, it is possible to calculate cross-vehicle dimensions, such as the crash length and the longitudinal beam track, for every vehicle configuration and design path. Out of this data the maximal or minimal value as well as the most critical design path and vehicle configuration can be determined. Within this configuration and design path, the fulfilment of the requirements is the most difficult.
For the crash length, the minimal value as well as the critical vehicle configuration and the design path, are calculated by the minimal sum of distances along one coordinate direction. To increase the validity of the crash length calculation, an additional deformation factor is introduced for every component. Consequently, the deformable length of a component (e.g. radiator) is added to the sum of distances. The deformation factors are derived from crash simulations and tests.
Without the deformation factor, the crash length, respectively the minimal sum of the distances can be also used for the identification of the maximal package vehicle configuration, with the maximal sum of component dimensions.
Additionally, the algorithm is able to analyse and output the effects of specific variants and components on the cross-vehicle dimensions. For example, the effects of the elimination of a specific engine variant on the crash-length can be evaluated similar to the analysis of individual dimensions (Figure 9).

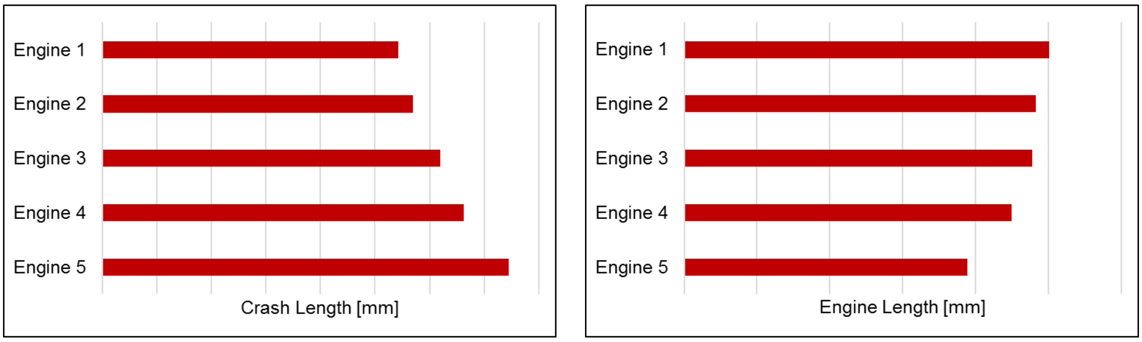

Figure 9: Effects of engine variants on crash- and engine length

With the analysis, the minimal required distances, the maximal component dimensions as well as the cross-vehicle dimensions are identified for each drivetrain- and vehicle architecture. Therefore, the geometric requirements can be outputted. In addition, the most critical design paths and vehicle configurations can be examined. Consequently, less critical vehicle configurations can be neglected afterwards. Therefore, the number of contemplated vehicle configurations can be reduced from over 100 to less than ten.

From the reduced amount of vehicle configurations, the one with maximum package is especially relevant. Besides there is also the maximum-requirement configuration. This specific configuration must fulfil both the regulatory general requirements and the aggravated specifications of consumer protection tests. This affects mainly the requirements to the distances and cross-vehicle dimensions. Due to the increased requirements, the component dimensions must be smaller, so that larger distances between the components are available, for the fulfilment of the increased requirements. Consequently, it is not possible to identify this vehicle configuration based on minimal distances, meaning experts must mark the affected components and distances in the database. Afterwards the dimensions can be compared with the ones from regulatory general requirements.

In addition to the derivation of the geometric requirements, based on the analysis, it is possible to compare the dimensions of drivetrains, with for instance combustion or electric engines as well as with front or rear wheel drive. A geometrical comparison of single components, such as in-line, v-type and electric engines, is also representable.

3.7 Visualization of Dimensional Chains

After the completion of the preceding steps, it is possible to visualize the cross-vehicle dimensions, the maximal component dimensions as well as the minimal required distances for each drivetrain- and vehicle architecture. Therefore, an abstract parametrical CAD-model of the vehicle front is built up (Figure 10).

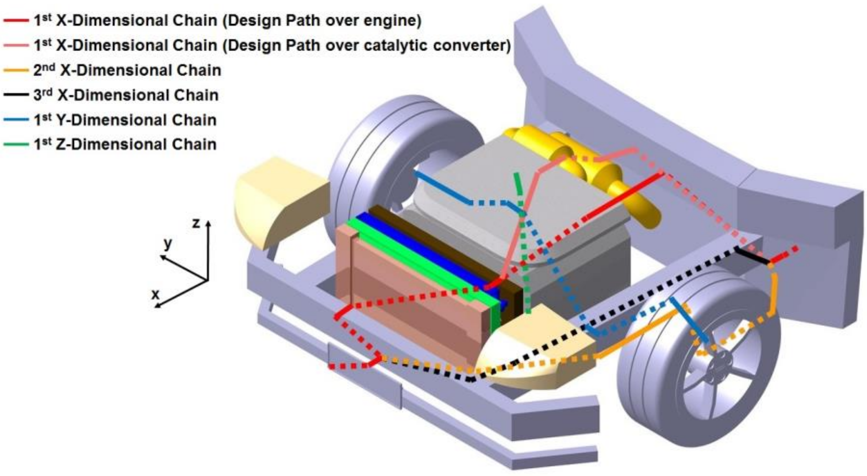

Figure 10. Parametric-Model for dimensional chains

The CAD model is presented in an abstract manner to focus on the significant elements. Using the parametric model, it is possible to display geometric requirements and to compare drivetrain- and vehicle architectures fast and efficiently.

4 CONCLUSION AND OUTLOOK

The methodology, exemplified in the case of a vehicle front, derives, analyses, compares and visualises the minimal required distances between components, the maximal component dimensions as well as the cross-vehicle dimensions for various drivetrain- and vehicle architectures. Therefore, the user can derive geometric requirements and compare dimensions of series vehicles, as a starting point of a new development. Thereby all necessary information about the most critical design paths and vehicle configurations are provided.

Focusing on the early stage of the development and the drivetrain architecture, the dimensional chains and design paths do not consider components with a high number of mounting positions. In addition, the deformations of the components, which would occur during a crash, are only considered by component deformation factors. However, massive deformable components such as component brackets, wires and hoses are neglected in order to increase the validity of the crash length calculation.

The results of the methodology do always depend on the design approaches and the properties of the examined series vehicles. Especially the model year of the vehicle affects the results, as legal and consumer requirements are time dependant. Consequently, results are not entirely transferable and comparable. However, as the properties are documented in the database as metadata, differences are comprehensible. To overcome the dependency on specific design approaches and vehicle characteristics, correlations between dimensions and vehicle or component properties, will be derived in the future. Subsequently geometric requirements as well as drivetrain- and vehicle architectures can be modelled and optimized based on a selection of vehicle parameters.

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