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PROCESS MODEL FOR CHANGE MANAGEMENT IN THE SYSTEM OF CHASSIS-MOUNTED PARTS OF COMMERCIAL VEHICLES

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Abstract

Due to the high amount of interrelations, such as spatial dependencies, material exchange, energy transfer and information flow, the chassis-mounted parts, located between the axles of a commercial vehicle, form a complex system. To use the limited installation space in an optimized way, which is restricted by the wheelbase and customer requirements, chassis-mounted components are grouped together in specified patterns, so-called layouts. As a consequence of the long product life-cycle of commercial vehicles, requirements concerning chassis-mounted parts change and modifications within the initially optimized layouts occur. To guarantee the robustness of defined layouts it is important to gain transparency concerning the consequences of changes. Therefore, this paper aims at developing a methodology which can visualise and quantify the dependencies between chassis-mounted parts. In the case that layouts must be rearranged, the methodology has to be able to assess the propagation of change within a layout in order to support the decision-making regarding the arrangement of the considered parts.

Keywords: Portfolio management, Platform strategies, Systems Engineering (SE), Change management, Commercial vehicles

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1 INTRODUCTION

Due to versatile costumer requirements, the commercial vehicle industry offers a diverse product portfolio. To cope with the demanded marked-based external variance, a large number of product variants was generated over time by manufacturers of heavy goods vehicles (HGVs), which led to a high internal variance. The chassis-mounted components (e.g. fuel tank, exhaust system), which are located between the axles and at the overhang of a commercial vehicle, were identified as a main source of the internal variance due to a multitude of component variants in combination with possible installation positions. So-called layouts, which represent a valid arrangement of chassis-mounted parts, are used for the management of the overall product portfolio. In order to reduce the customer-irrelevant internal variance and therefore economically realise the claimed diversity of commercial vehicles, the standardisation in positioning and modularisation of functionally similar chassis-mounted parts provides a promising approach.

The regarded parts form a complex system in every product variant because of geometric constraints, piping and wiring among them. During the product life-cycle from 20 to 25 years, modifications in this complex system are likely, e.g. because of changes in technology or government regulations. Hence, methods of complexity and change management are needed to support justified decisions concerning standardisation and modularisation of layouts which should remain stable over time. Hereafter, an approach is presented, which aims to enhance the transparency of the regarded system by visualising the relations and assessing the propagation of change to enable well-founded decisions regarding the arrangement of chassis-mounted parts.

1.1 Background: Challenges for standardisation due to changes over the product life-cycle

Compared to the automobile industry, trucks have significantly longer life-cycles. Over the time span of two decades, changes of some chassis-mounted parts can occur, e.g. due to government regulations. These changes can be the modification of the dimensions or the alteration of inputs and outputs of the regarded parts. These circumstances make it difficult to guarantee stable layouts of the complex system and to establish standardised installation positions for chassis-mounted components over time.

For instance, the implementation of the Euro 6 standard for the reduction of emissions in the European Union (2007) brought changes to the exhaust system. To fulfil the new regulations, a different exhaust gas treatment was required, which led to the growth of the exhaust system. This had further impact on the positioning of other chassis-mounted parts due to the limited installation space between the axles of a commercial vehicle. In consequence, new product variants had to be created. Hence, the modification of dimensions complicates the endeavours for standardisation within the system of chassis-mounted components.

1.2 Problem description

In the product development process of an international truck manufacturer many departments develop different chassis-mounted parts in various locations. Often, the knowledge about the relations between one chassis-mounted part and another stays internal within a particular department. After the final assembly, when all chassis-mounted parts are merged together and become an interacting, complex layout, there are manifold relations between all chassis-mounted parts which are not transparent at first sight. Not understanding the complexity of this technical system contains risks like a high amount of changes during the product life-cycle, wrong decisions and crisis in the product development process (Lindemann et al., 2009). Also, the generation of unnecessary product variants and rising complexity costs can be a possible result (Ehrlenspiel et al., 2014). One such change, or rather one additional variant, can cause several other changes to other components in terms of both their positioning and design. These cause-effect-circles in variance propagation lead to exponential growth of variance in the manufacturer's solution space over time. In order to guarantee the stability of defined layouts over time it is essential to handle the complexity and to be able to assess the consequences of changes within the regarded system concerning standardisation. Therefore, a model for the complexity management of the chassis-mounted parts is derived.

1.3 Research Methodology

The chosen research methodology consists of three pillars: Firstly, a methods group for modular systems comprising a researcher and two experts for product architecture in the company. Secondly, a technical expert group with a member of each department for chassis-mounted parts and thirdly, an interdisciplinary group for vehicle concepts at university. The presented method for the visualisation and the assessment of change propagation within the system of chassis-mounted parts was created by the methods group using the Munich Methods Model, which was developed by Lindemann (2009). The method was discussed with the experts group for chassis-mounted components concerning fallacies and risks within the implementation process in the company.

2 STATE OF THE ART

2.1 Existing approaches to visualise and manage complex structures

The complexity of a product is characterised by the following aspects: It is an attribute of technical products and increases with the amount and variety of system elements and relations. Furthermore, complexity results from a dynamic system behaviour enabling a variety of system states, arises from a lack of transparency in the description of the system and increases with the number of variants (Ehrlenspiel and Meerkamm, 2013; Lindemann et al., 2009; Malik, 2008). The mentioned aspects can lead to problems in the product development process, e.g. long process times and a high amount of changes due to uncertainty of system behaviour (Lindemann et al., 2009).

In order to visualise and manage the complexity in product design, options from the field of graph theory and matrix-based approaches exist. Both approaches contain the same information and can be converted consistently from one form to another (Andrásfai, 1991). The application of **graph theory**, as a section of mathematics, allows an intuitive way to visualise complex systems in a network. The elements are depicted through nodes who are connected via directed and undirected edges (Gross and Yellen, 2006). Edges can symbolise different kinds of relations between the nodes. In the case of technical products, Pimmler and Eppinger (1994) proposed four generic types of interaction between elements: spatial dependencies, material exchange, energy transfer and information flow. Furthermore, **matrix-based approaches** are a widely-used possibility for modelling complex systems. The Design Structure Matrix (DSM) provides the systematic mapping of elements and their relationships of one domain, which is a collective term for a subset of similar elements, e.g. components, documents or staff within a system (Browning, 2001). In addition, a Domain Mapping Matrix (DMM) connects elements of two domains. By the systematic arrangement of DSMs and DMMs, a Multiple Domain Matrix (MDM) of an entire system can be created (Lindemann et al., 2009). Drawbacks of matrix-based approaches arise from limitations due to the formalised visualisation, which only allows the display of a single type of relation per matrix. Moreover, direct and indirect linkages between elements cannot be shown together in one presentation. (Ghoniem et al., 2004)

2.2 Existing approaches to manage change propagation

Product architectures of commercial vehicles undergo numerous changes during the long product life-cycle. These changes can be successfully managed by selected methods of change management (Koh et al., 2015). Jarratt defines changes of technical products as "an alteration made to parts, drawings or software that have already been released during the product design process. The change can be of any size or type and can involve any number of people and take any length of time." (Jarratt et al., 2011, pp. 105–106) In contrast to changes, iterations are routine and constantly conducted during the product design process (Wynn et al., 2007).

Within complex structures, changes can cause further changes to connected elements. Thus, a chain reaction of change can propagate through the system. The behaviour of systems concerning change propagation (CP) is classified into two different types. Ending change propagation consists of "ripples" and "blossoms" where change is brought to conclusion within an expected time frame. Whereas so called "avalanches" of change lead to unending change propagation, which cannot be stopped by a given point of time. (Eckert et al., 2004) On a higher level of detail, Eckert et al. categorize components or sub-systems of a product into three approximate types with regards to their effect on change propagation:

- Absorbers: absorb more changes than they produce. Absorbers reduce the overall complexity of a change issue.
- Carriers: neither reduce nor add to the change problem. They merely transfer the change from one component to another.
- Multipliers: create more changes than they absorb. Multipliers increase the overall complexity of a change problem and potentially cause "avalanches" of changes.

The **Change Risk Plot**, developed by Clarkson et al. (2004), is an option to visualise change propagation within a system. It is a DSM-based approach to depict the influence of change between elements of a single domain. The entries in the matrix contain the combined risk originating from a change-initiating element to a change-receiving element. In this context, combined risk means that all direct and indirect linkages from one element to another are considered. The calculation of the combined risk is carried out by the **Change Prediction Method (CPM)**. Initially, a DSM of a regarded system is derived from the product structure to depict all possible direct propagations paths of change within a system. After that, the direct risk based on likelihood and impact of change is calculated for all components which have common interfaces. Next, an algorithm evaluates the indirect risk for all fields in the matrix by including intermediate elements as potential propagation parts from a change-initiating element to a receiving element. The addition of direct and indirect risk gives the combined risk displayed in the Change Risk Plot, which identifies high risk connections in a system. (Clarkson et al., 2004) Based on the entries in the matrix, key figures of the components can be calculated. Giffin (2007) proposed a way to classify the components of a system as absorbers, carriers and multipliers by means of this key figures. The CPM was successfully applied in the field of aviation industry to identify change-critical components of helicopters (Clarkson et al., 2004).

Furthermore, graph-based representations can be used to visualise change propagation. They simplify the assessment of indirect linkages or propagation paths between components compared to the presented Change Risk Plot (Ghoniem et al., 2004). The graph-based **Change Propagation Network** provides an adaptable display for direct and indirect propagation paths within a system depending on a selected root and focus component. In order to clearly display every path of propagation from a root to a focus element, the graph-based **Change Propagation Tree** can be used. These two kinds of networks were applied to identify critical connections of a diesel engine. (Keller et al., 2005)

2.3 State of the Art in complexity and change management at MAN Truck & Bus AG

MAN as a major producer of commercial vehicles faces the challenge of a highly diverse product portfolio, which is accompanied by low quantities of some product variants as a characteristic of the commercial vehicle industry. To manage the complexity arising from the high amount of product variants, MAN uses a highly modular product architecture, which consists of modular kits at full vehicle and component level within the product structure. (Förg et al., 2014; Kreimeyer, 2012)

Koh et al. (2015) used engineering change forecast to identify and prioritise components for modularisation. Their matrix-based approach maps change requirements to affected product components and converts the said matrix into a component dependency matrix showing the risk of engineering change. Subsequently, a ranking is derived, displaying the parts, which should be made more modular.

With the implementation of a model for the generic package space decomposition of commercial vehicles, MAN made first steps to manage the positioning and component variance of chassis-mounted parts, which were identified as a main source of internal variance. Through this model, unified geometrical references can be made in order to generate a holistic view on the regarded components. In the following, standardized layouts and positioning standards could be defined (Förg et al., 2014). Furthermore, a market-oriented approach to create vehicle architecture standards within the chassis-mounted components was developed by Stocker et al. (2016). The authors propose a systematic procedure, which includes geometrical standards such as positioning schemes and layouts, to enhance the effectiveness of modular kits by standardising the interaction of modules and other components within these kits.

The presented methods and approaches of MAN mainly use a general view on the complex product architecture and chassis-mounted parts for the determination of modules and standardised installation positions. Up-to-date, the manifold interdependencies and the consequences of changes within the system of chassis-mounted parts are expert knowledge of the responsible departments and not methodically taken into account during the definition of vehicle layouts.

2.4 Intermediate conclusion and research gap

Existing approaches to complexity management and change propagation offer opportunities to depict direct and indirect linkages as well as the risk of changes within the system of chassis-mounted parts. Currently, MAN does not systematically use these methods in the field of standardisation and modularisation of vehicle layouts. In consequence, there is no explicit visualisation of the interrelations within chassis-mounted parts and no assessment of the consequences of technical changes, which leads to uncertainties in defining architectural standards and modules. Hence, there is a need for action to create transparency in the system of chassis-mounted parts.

In the following, a software-supported process model is developed, implemented and validated with the ability to depict technical dependencies and change propagation in order to derive well-founded recommendations regarding the arrangement of chassis-mounted parts. The understanding of the overall system is expected to be increased and the decision-making process of modularisation and standardisation is supported by the proposed procedure.

3 PROCESS MODEL FOR VISUALISATION AND DECISION SUPPORT IN THE SYSTEM OF CHASSIS-MOUNTED PARTS OF COMMERCIAL VEHICLES

In this chapter the process model is developed step by step. The software-supported implementation by means of the software Soley Studio is also described for each phase of the development. Firstly, the **requirements** are defined, which the method aims to fulfil to close the research gap:

1. The process model should visualise all mutual dependencies of chassis-mounted parts.
2. The process model should display change propagation.
3. The process model should be capable to give recommendations for suitable combinations or modules of chassis-mounted parts.

Figure 1 gives a summary of the methods, inputs and outputs (represent the goals, which the procedure wants to achieve) of the process model.

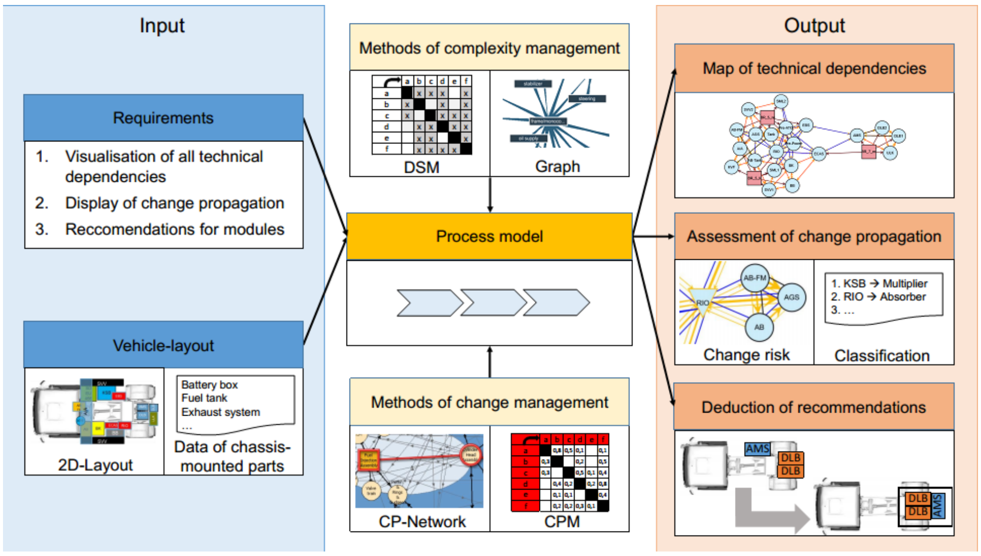


Figure 1. Overview: Input, output and used methods of the process model

On the left side, the inputs consisting of the said requirements and vehicle layouts are shown. The layouts contain information about the two-dimensional arrangement and associated data (e.g. length, weight, material) of chassis-mounted parts. Graph- and matrix-based display modes, shown in the middle of Figure 1, as methods of complexity management are used within the process model to reach the striven output of a map of technical dependencies, where all forms of relations between chassis-mounted parts are depicted. To assess change propagation and therefore cope with the target to visualise the change risk and classify the chassis-mounted components, an adapted form of the Change Prediction Method is applied. Based on the findings about dependencies and change propagation, recommendations regarding arrangements of future-robust modules in vehicle layouts can be derived. In the following, the given overview of the process model is explained in more detail.

3.1 Showing dependencies between chassis-mounted parts

In order to visualise all mutual dependencies between chassis-mounted parts (see requirement 1), the **domains** of the system have to be defined in a first step. The chassis-mounted parts themselves form a domain. Two criteria are defined to determine the elements of this domain: The components must be located between the axles or at the overhang of a commercial vehicle and they must also be directly or indirectly attached to the chassis. Following these criteria, 26 distinct chassis-mounted components were found, e.g. fuel tank, control units or compressed air tank. The installation space, which consists of defined rectangular areas based on the generic package space decomposition model, constitutes the second domain. A maximum of nine installation spaces of commercial vehicles with two front axles and a long overhang could be identified. Regarding the example in Figure 2, there are three installation spaces symbolised by the red boxes, which include the chassis-mounted parts. The last needed domain is the lead-frame of the commercial vehicle. It determines the provided installation space because its dimension specifies the number of axles and the length of the overhang.

After the definition of important domains, the elements of the system can be connected via different **types of relations**. Firstly, intra domain linkages of the chassis-mounted parts are considered. In this case, spatial dependencies exist when two components have an adjacent packaging space. This type of relation is layout specific as the structure of chassis-mounted parts normally changes per layout. A material flow is given if parts are connected through piping. Furthermore, an energy flow between two chassis-mounted parts exists if two components are connected by wire. The linkages of material and energy flow are generic, which means that they are valid for every layout in case the chassis-mounted components containing these linkages are present Secondly, inter domain relations can be found. The elements of the domain chassis-mounted parts are connected to installation spaces because this spaces contain the chassis-mounted components. Furthermore, the said parts are firmly bonded, form- or force-locked to the chassis, so that spatial dependencies result between these two domains.

Having set all relevant domains and relations, the striven map of technical dependencies can be created. Figure 2 shows an example of a given vehicle layout, which is transferred into a graph.

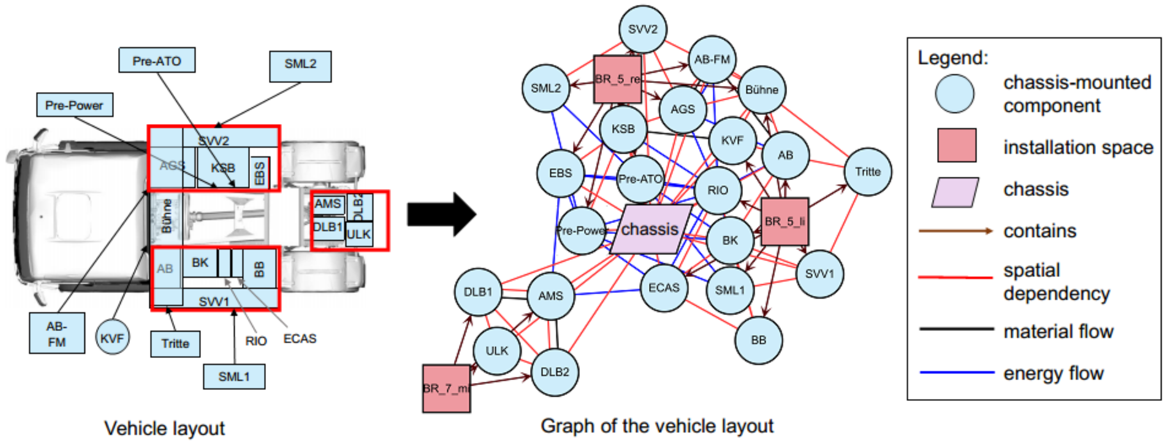


Figure 2. Deduction of a graph-based map of technical dependencies out of a vehicle layout

On the left, a two-dimensional layout is shown, which contains 22 chassis-mounted parts in three installation spaces. The data of the components (e.g. dimensions, weight, material) and all linkages concerning the material and energy flow belonging to the layout are available in tables whose information was acquired via expert talks at MAN. The spatial dependencies are derived from the given layout. In a next step, the collected information is translated into a graph depicted in the middle of the figure by means of the software Soley Studio, which can consolidate, structure and analyse complex data. This software imports the tables in a work flow and visualises the layout via nodes and edges based on the given information. The data of the components is saved as attributes of the nodes. Circles symbolise the chassis-mounted components, rectangles are installation spaces and the chassis is characterised by a diamond. The previously defined four types of relations (see legend of Figure 2) are visualised as the edges of the graph.

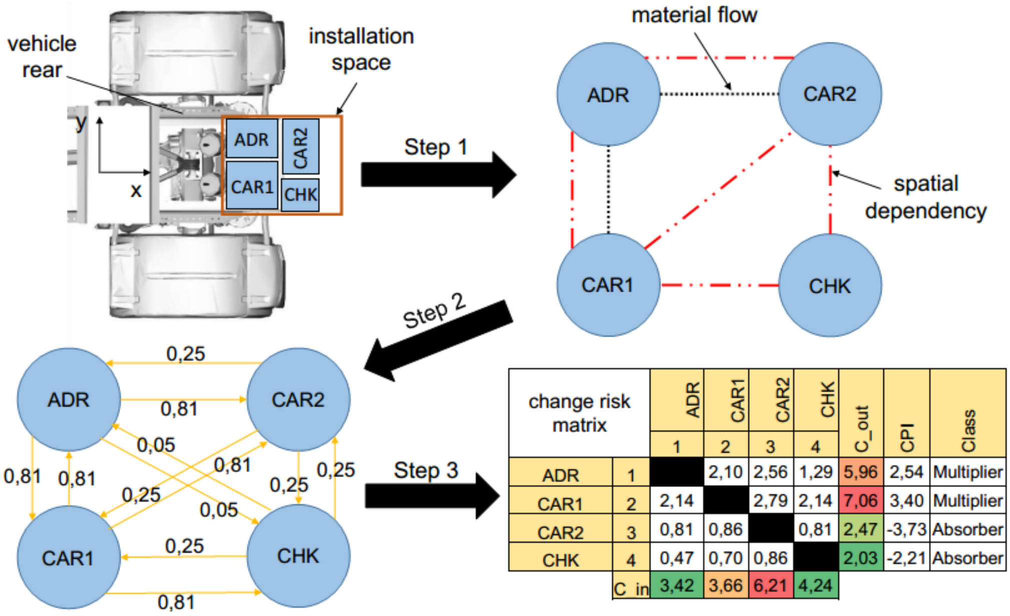
The visualisation in a network enables the further analysis of the interdependencies within the layout. Besides the direct linkages, also indirect dependencies can be made transparent in this form of representation. Thus, the complexity of the vehicle layout can be quantified by the number of elements and the amount of direct and indirect relations.

3.2 Assessing change propagation between chassis-mounted parts

In order to assess the consequences of change propagation, an adapted form of the **CPM** (see section 2.2) consisting of three steps is applied to create the chance risk matrix with key figures. A sub-system of chassis-mounted components located in the installation space at the rear of a commercial vehicle (see Figure 3 on the top left side) is regarded to illustrate the fundamental principle of the procedure.
Step 1: The map of technical dependencies has to be created as described in section 3.1. The exemplary system consists of four elements: An air dryer (abbr. by 'ADR'), two compressed air reservoirs (abbr. by 'CAR1' and 'CAR2') and Chocks (abbr. by 'CHK'). There are spatial dependencies given by the arrangement of the components and also material flows via pneumatic lines within this system as shown in the map of technical dependencies on the top right side of Figure 3.
Step 2: It is necessary to evaluate the changes between chassis-mounted parts in order to enable statements about change propagation. Therefore, a direct change risk between chassis-mounted parts is defined, displaying the risk from one chassis-mounted part (CMP1) to another chassis-mounted part (CMP2) in case CMP1 is modified. The values of the direct change risk (r) can be between 0 (the modification of CMP1 has no influence to CMP2) and 1 (the change of CMP1 will certainly change CMP2). Equation 1 shows the calculation of the direct risk:

$$r_{CMP1 \to CMP2} = p_{CMP1 \to CMP2} \cdot i_{CMP1 \to CMP2} \qquad (1)$$

The multiplication of the probability (p) by the impact (i) from a change initiating element (CMP1) to a change receiving element (CMP2) yields the direct risk. The values of the probability are set depending on the type of relation in combination with the available installation space. In the case of existing spatial dependencies and adjacent packaging spaces, there is a significantly higher probability of change (0.5 or 0.9) than by a material or energy flow or a joint installation space between two components (0.1). The impact symbolises the consequences of a change. If CMP2 can possibly be modified due to a change of CMP1, a mediocre impact (0.5) is defined.



change risk matrix		ADR 1	CAR1 2	CAR2 3	CHK 4	C_out	CPI	Class
ADR	1		2,10	2,56	1,29	5,96	2,54	Multiplier
CAR1	2	2,14		2,79	2,14	7,06	3,40	Multiplier
CAR2	3	0,81	0,86		0,81	2,47	-3,73	Absorber
CHK	4	0,47	0,70	0,86		2,03	-2,21	Absorber
	C_in	3,42	3,66	6,21	4,24			

Figure 3. Procedure of the three-step Change Prediction Method

A high impact (0.9) is given if CPM2 is certainly altered by a changed element CMP1. The numerical results of the direct risk between the chassis-mounted components of the exemplary system are shown in the directed graph on the bottom left of Figure 3.
Step 3: Finally, the combined change risk and key figures are derived from the graph of direct change risk. To calculate the combined risk between two components, theoretically all paths of propagation have to be taken into account. According to a recommendation of Clarkson et al. (2004), paths up to a maximum of three edges are regarded. All direct change risks within a path are multiplied to compute

the change risk of one path. All paths summed up yield the combined risk shown as an entry in the matrix on the bottom right of Figure 3 (e.g. the combined change risk from 'ADR' to 'CAR1' is equal to 2.10). To characterise the overall behaviour of chassis-mounted parts, three key figures are calculated based on combined risks. The outgoing change (C_out) of a component is defined as sum of the row entries (e.g. C_out of 'CAR1' is 2.14+2.79+2.14=7.06). The ingoing change risk (C_in) is the sum of the column entries (e.g. C_in of 'CAR1' is 2.10+0.86+0.70=3.66). Consequently, the Change Propagation Index (CPI) is calculated as the difference between C_out and C_in (CPI of 'CAR1' is 7.06-3.66=3.40). The CPI enables a classification of the chassis-mounted components into different change behaviours (Suh et al., 2007). A CPI greater than zero characterises an element as a multiplier ('ADR', 'CAR1'), which amplifies changes within a system. Carriers are neutral to changes and have a CPI, which is approximately zero. Absorbers ('CAR2', 'CHK') possess a negative CPI and reduce the issue of change propagation. The results of the combined risk, C_out, C_in, CPI and the classification by means of change behaviour of the exemplary system are depicted in the change risk matrix at the bottom right of Figure 3. Thereby, the process model is able to display the propagation of changes (requirement 2).

3.3 Deriving recommendations from the generated results for future-robust layouts

Based on the analysis of the results of Sections 3.1 and 3.2, recommendations for potential combinations and modules of chassis-mounted parts can be derived and well-founded decisions are supported (see requirement 3).

Deductions from the map of technical dependencies:

The map of technical dependencies contains information about the number of direct linkages (spatial dependencies, material and energy flow) within a layout, from which also data about indirect relations can be calculated. The amount of such linkages is an indicator of the complexity of a system (see Section 2.1). Thus, the quantified comparison of different layouts regarding the complexity becomes possible. In the case two possible layouts with identical material and energy flows but different spatial dependencies are considered to be used in future commercial vehicles (see Figure 4), the amount of direct and indirect dependencies gives evidence where a lower degree of cross-linking and therefore an easier management of the layout can be expected. In the given example, the number of indirect linkages up to the length of three is regarded (N_direct; N_indirect, L2; N_indirect, L3), which means that all relations up to a maximum of three edges between two components are taken into account. Layout 1 has a lower complexity due to fewer linkages in every considered dependency and is recommended to be chosen for future commercial vehicles.

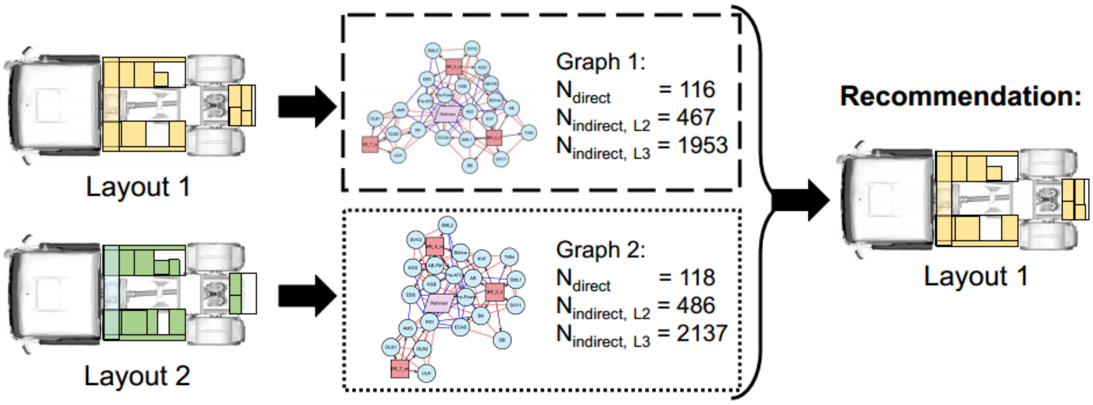


Figure 4. Comparison of the complexity of two vehicle layouts by direct and indirect linkages

Deductions from change propagation behaviour:

The analysis of the change risk matrix provides insights into possible recommendations for action concerning the arrangement of chassis-mounted parts. Elements, which are classified as multipliers have a greater outgoing than ingoing change risk. These components are likely to cause avalanches of changes. For this reason, modifications to multipliers should be avoided in order to prevent amplified propagation of change within the system of chassis-mounted parts. Figure 5 shows an example of a necessary change in a layout due to an increased need for packaging space of CMP1 in the limited installation space. If a selection of chassis-mounted parts (CMP2, CMP3, CMP4) can be chosen for a change, the component with the lowest CPI (CMP3) should be considered at first. With this decision it can be expected that a change of the strongest absorber in the regarded system causes the lowest propagation of change because the difference between outgoing and ingoing change risk is minimal.

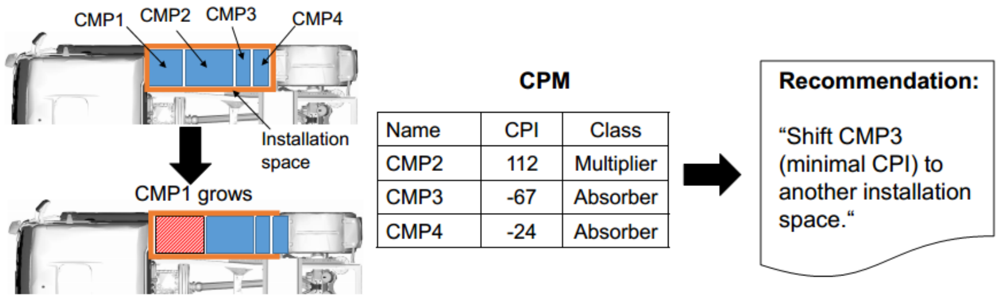


Figure 5. Recommendation for a shift of a component based on the comparison of the CPIs

3.4 Validation of the process model via use cases

The validation of the developed process model was carried out through two use cases derived from existing vehicle layouts of MAN. In each case, several changes to the existing layout were possible. These changes were analysed by means of the process model in order to make transparent decisions about the rearrangement of chassis-mounted parts. The first layout had to be changed due to an increased need for packaging space of the AdBlue tank, which resulted in exceeding the available total installation space. A decision had to be made if either the installation position of the battery box, the control unit for air management or the control unit for sensors and actors had to be swapped to the free installation space at the overhang of the vehicle. In the second case, battery and power electronics were added as new components to an existing vehicle layout. It had to be decided, which new arrangement is the most suitable for a future layout.

For both cases the map of technical dependencies were created and direct as well as indirect relations were calculated to measure the complexity of the layouts. Moreover, it was possible to assess the change risks between the components and subsequently derive the change risk matrix with key factors. Based on the two defined recommendations (see Figure 4 and 5), plausible and quantified advices to support the decision-making for reordered layouts could be given. The recommendations correspond to expert opinions from layout planning at MAN because the proposed modifications to the layouts are expected to result in minimal change efforts.

4 CONCLUSION AND OUTLOOK

This paper presents a method to support complexity and change management for engineering companies dealing with highly interconnected systems within their products as well as changes due to modified requirements during long product life-cycles. Therefore, a process model focusing on the complex system of chassis-mounted parts of a commercial vehicle was developed. It depicts the linkages of components and assesses the consequences of changes in order to support the decision-making regarding the arrangement of the considered parts in the case that vehicle layouts have to be reordered. A graph was created to visualise the technical relations of the regarded system. It shows spatial dependencies, material and energy flows between the chassis-mounted parts, which are located in specified installation spaces. Furthermore, the amount of direct and indirect linkages was calculated to quantify the complexity of the system. The assessment of changes was carried out by the Change Prediction Method. As a result, a change risk matrix could be derived containing key figures to categorise the elements of a layout into different change propagation behaviours. By analysing the generated findings, recommendations concerning the assembly of future chassis-mounted parts were derived. The model was validated through two use cases. It could be shown that the model has the ability to depict technical dependencies and change propagation of the regarded layouts. In the case of necessary changes, the process model derived well-founded and plausible recommendations for rearranged layouts.

However, during the validation of the model potentials for improvement were discovered. The information about spatial dependencies was obtained by two-dimensional layouts (see Figure 1). In order to improve the determination of geometrical relations, three-dimensional layouts could be analysed in the future. Furthermore, the direct change risk was exclusively defined based on the interdependencies in a vehicle layout. Further information sources like empirical values concerning changes from past projects or expert opinions at the company could be used to check the obtained values for plausibility. The presented process model will be included in a tool chain for the early concept phase of commercial vehicles developed by the department of product architecture at MAN in collaboration with the Institute of Automotive Technology at the Technical University of Munich (TUM).

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