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Applying and analyzing A3 Architecture Overviews in a complex and dynamic engineering environment

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Abstract. This research analyzes the implementation of the A3 Architecture Overview (A3AO) method at Mercedes-Benz R&D. An A3AO captures, organizes and presents architectural information of a complex system on an A3 sized paper. The goal is to communicate architectural knowledge in a human-oriented way, assuring all stakeholders obtain and maintain a common understanding and overview of the system.

The A3AO method was applied to 'high-voltage charging systems'. Two higher-level A3AOs and three A3AOs on more in-depth topics were created. The charging system is considered to be representative for the engineering environment of Mercedes-Benz R&D. General results showed that the A3AO method is useful in documenting and communicating architectural knowledge of a system. It furthermore produces good overviews of a complex system, which can be used in discussions and to train new employees.

The two main impact factors ensuring sufficient added value are the format and the integration in the development process.

Introduction

The automotive industry is evolving rapidly; vehicles are becoming more intelligent, safer and more sustainable (Broggi, et al., 2016). These developments result in an increasingly more complex high-tech product with a variety of disciplines developing one system. The engineers involved often focus on their own subject and, typically, do not look at the system as a whole (Muller, 2011), which leads to a sub-optimal system design. Additionally, they often struggle when communicating across domains, which leads to costly system integration.

Developing complex high-tech systems requires a multidisciplinary approach. This approach includes good designers and specialized engineers, and systems architects who create and maintain an overview of the entire system.

The systems architect ensures that all stakeholder requirements are met and translated into a systems architecture (Muller, 2004). However, the complexity of this task is captured in the literature by stating a variety of tasks, responsibilities and deliverables that are all rather intangible (Muller, 2011). This complexity and the lack of a widely accepted human centered systems architecting method focusing on intelligible communication between people means that the success of an architecture heavily depends on the insights and experience of the systems architect himself. Furthermore, often the systems architects keep most of the architectural information in his head, making it harder to communicate this information and resulting in an even bigger dependency on the architects themselves. Thereby, a good systems architecture is useless if not communicated to all stakeholders.

Company description. Daimler AG is one of the world's most successful automotive companies. With its divisions Mercedes-Benz Cars, Daimler Trucks, Mercedes-Benz Vans, Daimler Buses and Daimler Financial Services, the Daimler Group is one of the biggest producers of premium cars and the world's biggest manufacturer of commercial vehicles with a global reach. Daimler invests in the development of efficient drive trains with the long-term goal of locally emission-free driving: from high-tech combustion engines about hybrid vehicles to electric drive trains powered by battery or fuel cell. Furthermore, the company follows a consistent path towards intelligent connectivity of its vehicles, autonomous driving and new mobility concepts. In 2017, the Group sold around 3.3 million vehicles and employed a workforce of more than 289,300 people; revenue totaled €164.3 billion and EBIT amounted to €14.7 Billion. (Mercedes-Benz Cars, 2017). Daimler sets out to have over 10 new electric vehicles by 2022, be the first manufacturer to produce an electric truck in series production and an electric bus will enter the market this year (Daimler AG, 2018).

Current premium cars are highly complex; they can contain up to 200 different systems, each containing multiple components implemented by several ECUs and totaling millions of lines of software code (Charette, 2009). With the advent of electrification, fully autonomous and fully connected vehicles, this complexity will only increase (Traub, et al., 2017). To achieve these ambitious goals, all systems and components have to be aligned and a variety of disciplines needs to collaborate. Creating and communicating the systems architecture in an intelligible manner is essential.

There are several methods that deal with the design of complex systems, for example Design Structure Matrixes (DSM) (Lindeman, 2016) and SysML (Anon., sd). Both are formal approaches focusing on a detailed description of a system. However, they do not focus on the intelligible communication of information between humans. Therefore, this research investigates the effect of implementing a more human-oriented approach of communicating and documenting architectural knowledge of a system at a sophisticated engineering organization such as Mercedes-Benz R&D; A3 Architecture Overviews.

A3 Architecture Overviews. The A3AO method is a tool to capture, organize and present architectural knowledge of a system and is to be used by the systems architect (Borches & Bonnema, 2010). It captures complementary views including a functional, physical and quantificational view on an A3 paper. The architect uses the A3AO to communicate architectural knowledge in an effective human-oriented way, such that all stakeholders obtain and maintain a common understanding and overview of the system, and discussions on the system are triggered (Bonnema, 2010).

The size of the A3 paper (297x420 mm) forces the architect to present relevant information solely, while it provides sufficient space for details and specific information. According to the A3AO cookbook created by Borches (Borches, 2009), both sides of the A3 paper are used, as can be seen in Figure 1. The left view is the summary, which predominantly contains text and starts with an introduction to the topic. Furthermore, the views of the model side (right figure) are elaborated and the stakeholder concerns, design decisions, a roadmap and references are described. The model view contains complementary visual overviews of the system: a functional, physical and quantificational view and key parameters.

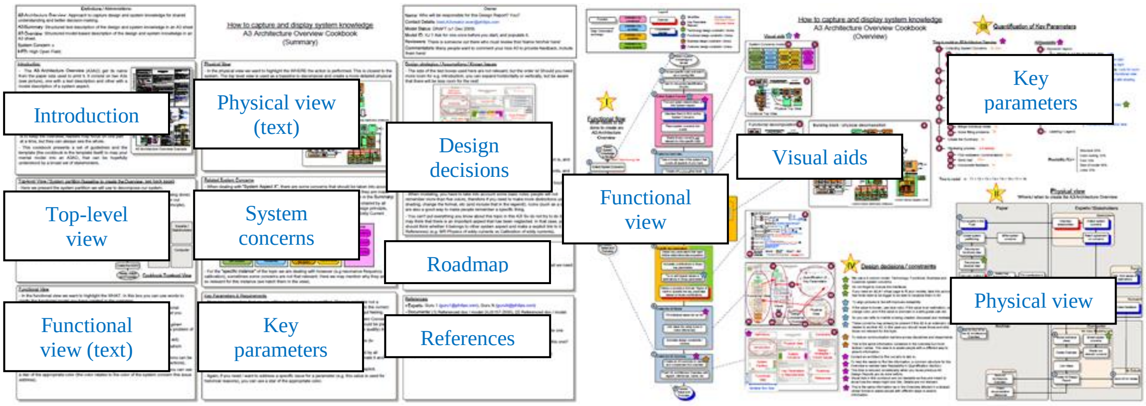

Figure 1: A3AO example. Left: Summary, Right: Model view (Borches, 2009)

Constructing an A3AO is an iterative process, with the architect being responsible for the content. Initially, the architect gathers requirements on the system from all stakeholders and creates a preliminary A3AO out of the information. The A3AO is adapted and improved by discussing the overview with the stakeholders involved. This process is an important part of the A3AO method, since it triggers discussion on the system. The A3AO can be regarded as finished when no new information is added or deleted during an iteration.

Research goal. The goal is to investigate whether a global engineering organization with a high production volume and highly complex, dynamic and safety-critical product, i.e., Mercedes-Benz R&D, can benefit from implementing the A3AO method. This research contributes to the Systems Engineering Body of Knowledge (SEBoK) (Muller, 2012), which is an accumulation of research done on systems engineering. Comparable research on A3AOs has been conducted in areas such as the gas & oil industry (Singh & Muller, 2013) (Wee, et al., 2015), manufacturing (Polanscak & Muller, 2017) and maritime industry (Kristian Frøvold, 2017). This research showed that stakeholders are interested in systems engineering methods such as A3AOs. However, the interest seems not significant enough to adopt the method on a large scale to date (Muller, 2012). The application of A3AOs in a company such as Mercedes-Benz had yet to be researched, which lead to the main research question: to what extent can A3 Architecture Overviews aid the development process within a large, complex and dynamic engineering environment?

Additional to the general effects of the implementation, impact factors that contribute to these effects are examined. Impact factors can either have a positive or negative effect on the success of the A3AOs. The general effect of the A3AOs combined with the distilled impact factors lead to a generic conclusion on the effect of applying A3AOs in such an environment.

Research Method

To investigate the effect of A3AOs within Mercedes-Benz, the 'industry-as-laboratory' approach is used (Muller & Heemels, 2007). According to this approach, the actual industrial setting is used in which the researcher works closely together with the systems architect and becomes part of the team. Using this approach, the researcher obtains qualitative feedback firsthand and can place the observations within its context.

The high-voltage charging system is considered to be a representative case to apply the A3AO method on. Therefore, the researcher became part of the E/E-systems architecting team within the eDrive department of Mercedes-Benz for six months. Within those six months, five A3AOs of the charging system were created. The charging system ensures that the vehicle's high-voltage traction battery is charged while the vehicle is parked and connected to a charging station. Due to rapid developments in this field, driven by different types of charging and different regulations worldwide, the charging system is considered a representative case for a complex and dynamic environment within Mercedes-Benz R&D.

All A3AOs are constructed and evaluated according to the same process, as depicted in Figure 2 and described below.

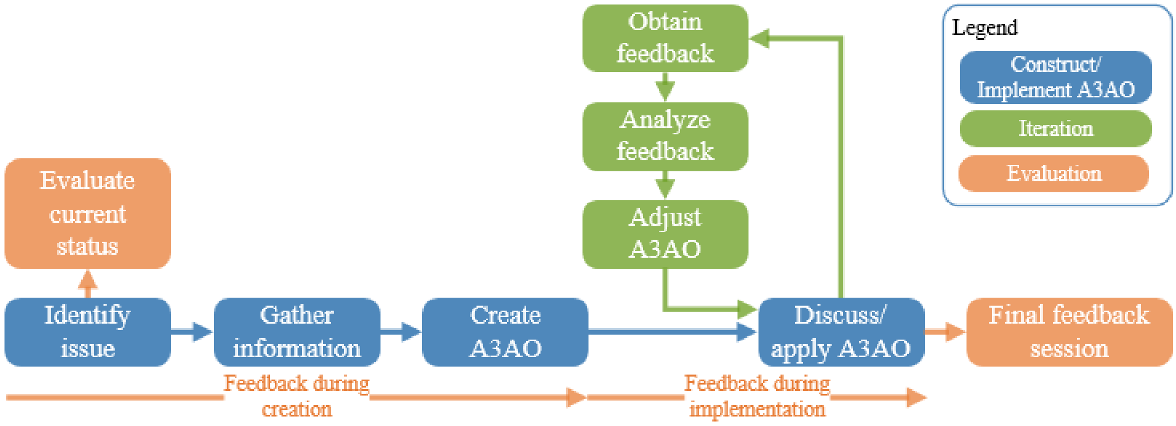

Figure 2: Research method

Constructing an A3AO contains several steps, as described below:

- **Identify issue:** The A3AO method can be applied to every complex engineering environment where people experience a lack of overview and problems with communication. Management of Mercedes-Benz observed those issues within the charging system department. In total, five topics are identified of which an A3AO is created.
- **Gather information:** Next step is gathering information on the topic identified. This is done by a combination of in-depth interviews with experts and by documentation, provided by experts and management. Within this research, for every topic at least one expert was interviewed using open questions on the topic. Depending on the topic, available documentation was provided and evaluated.
- **Create A3AOs:** When information is gathered, the relevant information is abstracted and converted into a first version of the A3AO according the A3AO cookbook, shown in Figure 1. However, experiences showed that for different topics other structures are possible as well. Therefore, variations on the format are made upon insight and creativity of the researcher and stakeholders involved. Within this paper, the A3AO figures blur (part of) the images due to reasons of confidentiality.

Iteration process. For each A3AO, several iterations are made. In this research at least 3 for each A3AO. The more iterations, the more complete and detailed the A3AO becomes, but also the more time it consumes to create. Each iteration contains the same steps. First, the A3AO is presented to the stakeholders, who provides feedback on the content, structure and lay-out. Afterwards, this feedback is analyzed and the A3AO is adapted if necessary. This process is repeated until there is no new information added or removed. Feedback sessions are held both planned and unplanned.

Evaluation process. Literature states that research in systems engineering often contains 'soft' human factors (Muller, 2013). Therefore, it can be a challenge to obtain data and results which can be used for analysis. For this type of research, a variety of formats can be used to obtain results, varying from free to standardized (Muller, 2013). For this research, a combination of open and more structured techniques are chosen, as can be seen in Figure 3. More open feedback, such as observations and open interviews, ensures the researcher to keep an open mind and be as little biased as possible. The open feedback is complemented by quantifiable data in the form of surveys. To evaluate the observations and statements by management on the current situation, a short survey was conducted among 12 employees. The survey contained three statements regarding finding current system information, communication across disciplines and current system knowledge. Observations and experiences during the construction and iteration of the A3AOs were supported by surveys on the content, lay-out and usefulness of each A3AO. Feedback on the A3AO method in general was gathered by observations, complemented by a final feedback session. This included an open interview and a survey of seven statements on the A3AO method held among fifteen stakeholders.

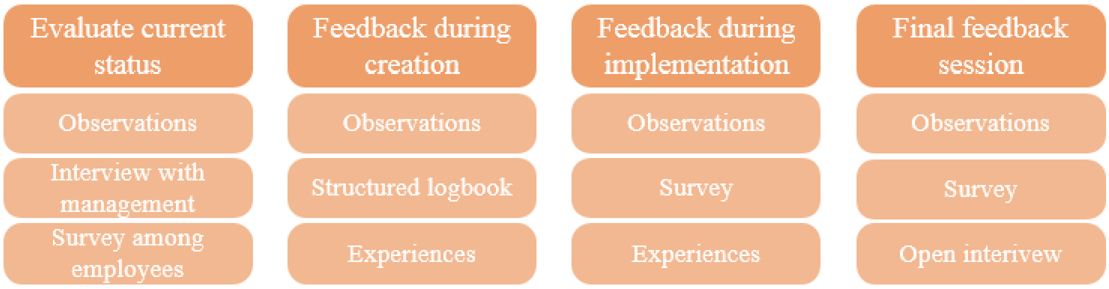

Figure 3: Overview of evaluation techniques

Data analysis. Results from observations, experiences and interviews are combined an analyzed to determine general trends. These trends are found by clustering comparable data, eventually leading to the impact factors. The data from the surveys is analyzed using the Net Promotor Score (Muller, 2013). With this method, participants who rated the statement with ‘strongly agree’ are regarded as promotors of the statement, while ‘neutral’, ‘disagree’ and ‘strongly disagree’ are considered to be complainers. The NPS can be calculated by subtracting the number of complainers from the number of promotors (NPS = #promotors - #complainers). The outcome of the statement is considered positive when the NPS > 0. The NPS is applied to all surveys concerning statements on the quality of a certain solution or characteristic. The statements on the current situation are, therefore, not analyzed by the NPS, but by a numerical analysis.

The High-Voltage Charging System: A Case Study

The high-voltage (HV) charging system provides electrical energy from an external source to a plug-in or electric vehicle during standstill. This energy can be used to charge the HV traction battery, or to supply energy to other vehicle functions such as the low-voltage (LV) battery or for heating or cooling the vehicle’s interior (preconditioning). Furthermore, a charging system can support reverse power transfer, meaning that energy is transferred from the vehicle back into the grid. Charging can be done conductively (AC or DC) or inductively, or by a combination of those. For conductive charging, four major global regions of interest (Europe, USA, China and Japan) have different charging plugs for both AC and DC charging. This also includes different charging protocols to communicate with the charging infrastructure. Furthermore, the charging system interacts with the user using the vehicle’s own user-interface or using an app deployed on a smart device. The charging system can also deal with smart charging, taking into account for example tariff tables to control the charging process.

These characteristics of the charging system shows its complexity. This complex system must be packaged within a relatively small product (the vehicle) together with all other vehicle systems. Additionally, customers physically use the system themselves, making safety a critical aspect. Furthermore, the development team has to deal with different project-schedules for different vehicle models, combined with varying development schedules of suppliers.

The charging system department

Besides the complex characteristics of the charging system itself, the development team also has to deal with a diverse engineering environment. For the development of the charging system, a variety of employees with different functions in different teams have to collaborate. For example, component engineers are responsible for an entire component, while hardware and software engineers are responsible for specific parts of such a component. Furthermore, there are specialized engineers responsible for specific functions, for example smart charging or functional safety. The charging systems architect is responsible for the end-to-end architecture of the charging system, while domain architects are responsible for integrating the charging system into higher levels of the overall vehicle architecture. In addition to these roles, other stakeholders in, e.g., marketing & sales, strategy, production and maintenance are involved in the engineering processes as well.

Current challenges

The way to deal with complexity is partitioning: dividing the big problem into smaller manageable pieces. However, dividing something into smaller pieces also results in interfaces and dependencies between those pieces. In the case of the charging system, this leads to the complex engineering environment described above. Achieving a common and consistent understanding of the system, its design, its properties and other relevant aspects is extremely challenging. For example, the researcher experienced that during some meetings, not all participants had the same understanding of the system while at the same time being eager to dive into details immediately. This resulted in unstructured meetings initially, where a lot of time had to be spend upfront on getting everyone on the same page, or, worse, in some attendees silently dropping out of the meeting.

The researcher also observed that a lack of a common and consistent understanding of the system at the same level of abstraction can lead to misunderstandings amongst different stakeholders. For example, some technical experts freely used complex signal names when discussing functional behavior typically without considering that such signal names were not understood by other stakeholders.

The main source of documentation accessible to the researcher while gathering system information was a 500-page DOORS document, containing over 4000 system requirements in textual form. Although this list is required in the daily work of an engineer, it only gives a poor overview of the system. A second form of documentation were PowerPoint presentations. The information in these presentations varied heavily with each topic; some PowerPoints gave good information and a clear description of the topic, while for other topics there was no documentation at all.

To validate whether the observations and experiences were generally acknowledged, a short survey was conducted among 12 employees. They were all familiar with the charging system to some extent, however, they were from different teams and departments. Three statements regarding finding current system information, communication across disciplines and current system knowledge were given, as shown in Figure 4.

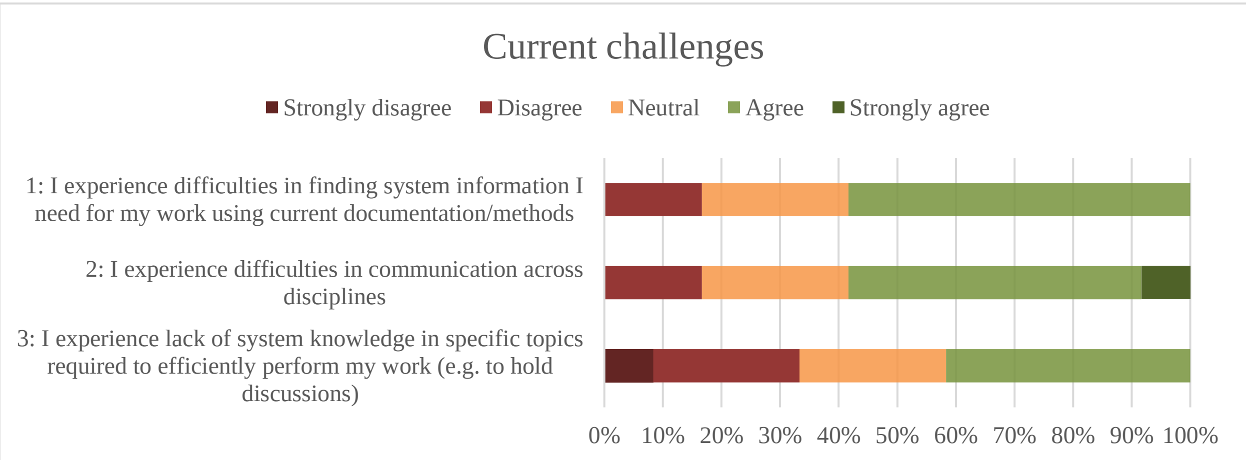

Figure 4: Survey on current situation (number of respondents = 12)

Figure 4 shows the result of the survey. For the first statement, the majority of the survey respondents agreed that they have difficulties in finding system information in current documentation, while less than 20% disagreed with the statement. The same observation can be made for the second statement on experiencing problems with communication across disciplines, but with nearly 10% strongly agreeing with the statement. This means over 50% of the employees have trouble in finding system information and in communication, showing there is a need for improvement. Furthermore, over 40% experiences lack of system knowledge in topics which they should master, while over 30% state they do not (strongly) agree. This means over 40% can improve their work efficiency by improving their level of system knowledge, again showing the need for improvement.

A minority exists that does not agree with the statements made. Discussing this outcome with management lead to a possible explanation: In a very dynamic and hard core engineering environment many employees learn to live with the deficiencies and shortcomings of the established engineering processes. The lack of examples of intelligible documentation and the lack of time to explore such documentation leaves the typical engineer content with what he has. This was a key motivation for the research reported in this paper.

Figure 5 shows an overview of the issues observed within the charging system department. These issues correspond with the intended goals of the A3AO method; improving the documentation and communication of architectural information and, thereby, improving the overview of a system. By proper documentation, system information would become easier to find and can be used to train new employees. By applying the method and showing the advantages, employees should automatically see the benefits of the method, making them more aware of their current issues.

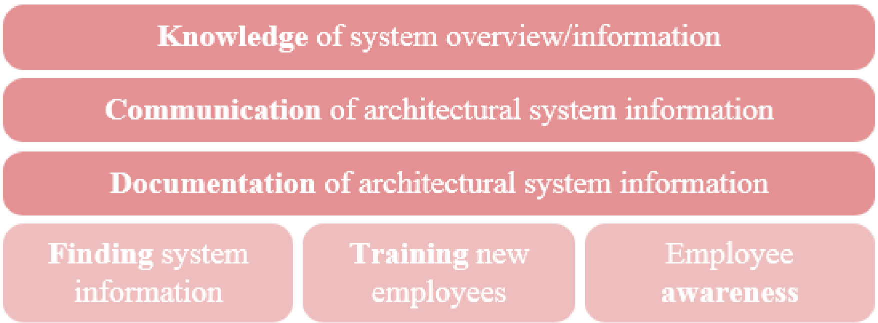

Figure 5: Overview of current development issues regarding architectural system information

A3 Architecture Overviews created

A total of five A3AOs were created on three different levels of technical depth (cf. Figure 6). First, two higher-level A3AOs were created to give an overview of the entire charging system. These A3AOs were created to be used by stakeholders who are less familiar with the topic, or by experts who require high-level system knowledge. Furthermore, the A3AOs can serve as a start of discussion early in the design process. Finally, the A3AO method was applied to three topics that were ongoing while the research took place (L2DX). This enabled the researcher to actively take part in the discussions to construct the A3AOs.

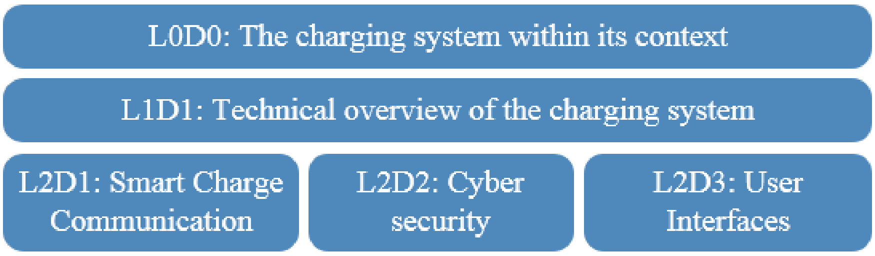

Figure 6: Overview of A3AOs created

Each A3AO has its own characteristics regarding structure, models used, usage of figures, text, colors and icons. This Section describes the characteristics of each A3AO. As stated before, these differences enable the researcher to determine impact factors. Due to reasons of confidentiality, details and numbers within the A3AOs are not shown and figures are abstracted or camouflaged.

Level 0 (L0D1) A3AO: The charging system within its context. The highest level A3AO describes the key architectural concerns of the charging system. The goal is to provide readers with key aspects that the charging system team has to deal with; hence, the main target audience are people who are not familiar with the topic. Figure 7 shows the structure of the one-sided A3AO. The large rectangle in the center summarizes the topics described in the case study. The reason for this structure instead of following the A3AO cookbook is the fact that this A3AO deals with multiple different topics, which are not easily put in a functional view. Therefore, we suggested a large center box as introduction and overview of the topic, surrounded by boxes that contain the key aspects.

The attention of the reader to the center box is drawn by a thicker line around the box and a bigger circle stating number '1'. Throughout the text in the introduction, circled numbers are used to guide the reader through all surrounding boxes. To visualize the system properly, pictures of the system are shown in the introduction box. Furthermore, more abstract representations of each topic are provided in the surrounding boxes. The circled numbers and center box as introduction provided sufficient information and guidance, hence, no explanatory back page was required.

Figure 7: Structure of L0D1 A3AO; **Characteristics:** Version: 5 / Feedback sessions: 7

Level 1 (L1D1) A3AO: A technical overview of the charging system. The second A3AO gives a technical overview of the charging system. It is intended for a broad audience, for example people who are less familiar with the charging system, or experts who need a higher-level overview. The format includes a summary side, which guides the reader through the A3AO, and, therefore, is well suited for self-study of new employees.

The largest part of the model page is the functional architecture (left column), as can be seen in the right picture of Figure 8. It gives a dynamic overview of the entire charging process, with all functions to be executed for a complete charging cycle. The process is divided into three phases; connecting with the infrastructure, controlling of the charging process and disconnecting from the infrastructure. Icons are used for a quick and easy understanding of each functional block. Furthermore, key parameters, such as charging power and hardware specifications, are shown. The physical overview shows an abstract placing of the charging related components in the vehicle as well as their interconnection as part of the communication architecture. A legend explains abbreviations and colors used.

The summary side starts with a top-level overview of the system including the division of the charging process into three phases mentioned above; connecting, charging and disconnecting. This leads to an elaboration of the functional view including three graphical representations. Next, the physical and networking overview are explained in the column in the middle. A link between the textual side and the models is made by an abstract view of the models in the textual description. Below, the general system concerns are elaborated, which strongly correlates with the topics on L0D1. In the right column, key parameters and features are stated, focused on charging features and charging times, complementing the key parameters on the model side. Last, upcoming innovations are written in the roadmap and references are stated. As Figure 8 depicts, the summary side contains primarily text, complemented by several graphics.

Figure 8: Structure of L1D1 A3AO; **Characteristics:** Version: 8 / Feedback sessions: 12

Level 2 (L2D1) A3AO: Smart Charge Communication. The first in-depth topic is the partitioning of smart charge communication (SCC) functions between different software modules. Smart charging summarizes charging functions, which are more intelligent than merely plugging in the connector and charging with maximum power. Examples are automatic payment, inclusion of tariff tables, reservation of charging stations, and communication with the user. These functions lead to sophisticated communication amongst several components within the vehicle. A question was whether a repartitioning of functional blocks would lead to simpler communication relationships. The researcher attended five workshop-like meetings analyzing the current and a potential new partitioning and supported these discussions with the proposed A3AO.

First, an overview of all charging functions relevant for smart charge communication was created. The topics were determined within the first SCC meeting, and further elaborated and organized by the researcher. The overview can be seen at the top-left of the left side shown in Figure 9. Below the functional overview, a physical overview of both hardware and software modules is depicted to ensure an equal high-level understanding of all stakeholders. The biggest part of the A3AO consists of the partitioning of the functions. The A3AO created displays the first three SCC functions. The upper part shows the current partitioning of these functions, including signal flow required to execute the functions. The lower half provides space to draw the new partitioning interactively. The colors used for all components and software modules matches the colors used in the physical overview and the other A3AOs.

The backside of the A3AO (right picture in Figure 9) contains additional information of each of the three functions. The type of information displayed depends heavily on the specific topic and is up to the owner of the A3AO to determine. Again, colors and block shapes used correspond to other A3AOs, as depicted in the legend. Furthermore, circled numbers used in L0D1 for referencing are used again to link different types of information for each function throughout the A3AO.

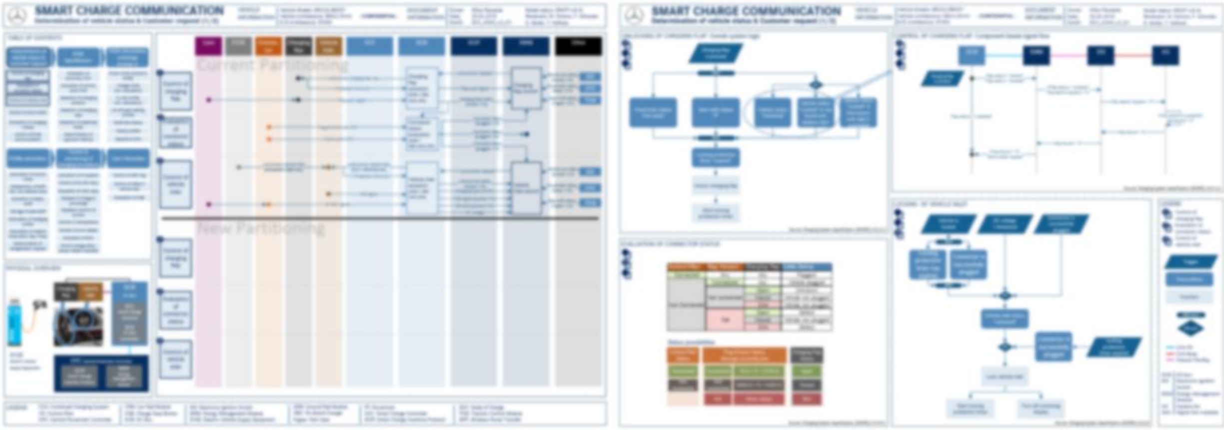

Figure 9: Structure of L2D1 (SCC) A3AO; **Characteristics** Version: 4 / Feedback sessions: 5

Level 2 (L2D2) A3AO: WPT Cybersecurity. The second in-depth topic is cybersecurity of the wireless power transfer (WPT) system. Cybersecurity is required to minimize the success rate and potential impact of cyberattacks. It protects the system against theft of user- and vehicle data, theft of components, theft of the vehicle, and manipulation or interruption of functions. This required an overview that illustrates the security concerns, and where in the architecture attacks can take place.

Because multiple topics are required to be put on the A3AO, a structure similar to L0D1 was chosen. Figure 10 shows a central box at the mid-left of the paper. This shows a physical overview containing relevant WPT components and its internal and external interfaces. It includes similar colors and icons as used in other A3AOs, as well as a thicker line surrounding the box to draw attention to it. Contrary to L0D1, it does not contain circled numbers to guide the reader throughout the A3AO. The boxes surround the central box display the security concerns, attack surfaces and proposed measures, divided into five different topics (which cannot be stated due to reasons of confidentiality). Each are displayed using a combination of text and visualizations. A legend explains abbreviations.

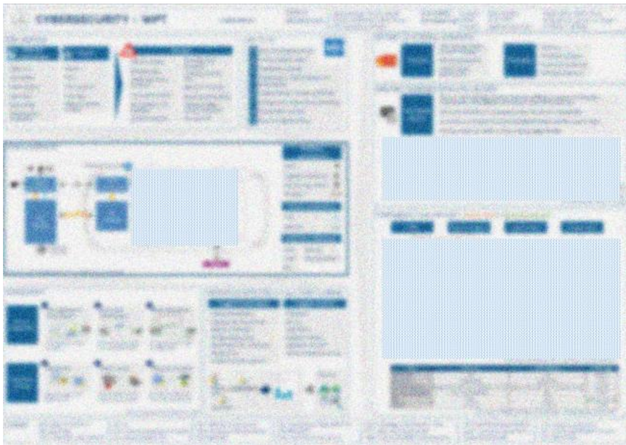

Figure 10: Structure of L2D2 (Cybersecurity) A3AO; **Characteristics:** Version: 3 / Feedback sessions: 4

Level 2 (L2D3) A3AO: User Interfaces. The last A3AO created shows the User Interfaces (UI) of the charging system, and what type of information is exchanged.

The structure of this A3AO is similar to the previous smart charge communication overview (L2D1). It shows an overview of functions, including the partitioning of where the function is implemented (Figure 11). In the center, a physical overview using real pictures shows the places where user interaction takes place. Surrounding the physical overview, all information that is exchanged is categorized and listed vertically. Horizontally, the places where user interaction takes place are showed using the same pictures as in the physical overview. After completion, the overview becomes a table showing which information is exchanged at each location. Furthermore, the functions are divided into two categories; functions that are displayed to the customer (blue columns), and functions where the user can give input into the system (grey columns). Again, a legend explains abbreviations.

Figure 11: Structure of L2D3 (UI) A3AO; **Characteristics** Version: 3 / Feedback sessions: 3

Results

Feedback on each specific A3AO

For each A3AO, a survey was conducted including several statements on the characteristics of that specific A3AO. The Net Promotor Score (NPS) is shown for each statement of all five A3AOs in Table 1. For the two higher-level A3AOs (L0D1 & L1D1), eight interviewees filled in the survey. For L2D1 and L2D2 three respondents filled in the survey, while for the last A3AO one respondent filled in the survey.

Table 1: Net Promotor Score of statements on each specific A3AO

Statement (# respondents to specific statement)	**L0D1 (8)**	**L1D1 (8)**	**L2D1 (3)**	**L2D2 (3)**	**L2D3 (1)**
1: The A3AO gives a **good overview of the topic** addressed	3	4	2	1	0
2: The A3AO gives a **better system overview compared to current documents/methods**	3	3	0	0	1
3: The **amount of information** on the A3AO is sufficient	7	8	2	-1	1
4: The A3AO is **easy to understand**	1	1	1	-1	0
5: The A3AO is **easy to navigate**	3	2	1	-1	1
6: The A3AO is **helpful for understanding the topic** at hand	1	1	2	0	0
Usefulness of:					
1: Multiple views in 1 overview	0	3	0	2	1
2: Colors used	5	5	0	0	0
3: Icons used	6	4	0	1	0
4: Images/visuals used	3	2	0	1	0
5: Empty spaces	-3	-1	0	-2	0

L0D1 (Context). Interviews held on L0D1 revealed that the A3AO gives a *good high-level overview* for people who are not familiar with the topic, for instance new employees or higher management. Furthermore, the interviewees pointed out that it was useful that the A3AO captured *several topics on one page* and that it was easy to comprehend.

The statements are confirmed by the results of the survey, as shown in Table 1. It shows that the A3AO gives a good overview of the topic, better than current documents available. Furthermore, the A3AO is *easy to navigate* and understand due to the colors, icons and visuals used. Especially the circled numbers were highly appreciated. Interestingly, the survey does not clearly confirm the response that it is useful to have multiple views in one overview, while this was pointed out during the interviews. The reason for this can be that not all boxes were equally regarded as useful.

Besides the survey statements in Table 1, the respondents were asked to rate the usefulness of each specific box of the A3AO as well. Three out of the ten boxes were not regarded as useful (NPS < 0). The A3AO leaves some space for making notes or drawings, however, this was not regarded as an advantage for this A3AO. This could be due to fact that this A3AO states facts that are generally known and agreed upon, and therefore does not trigger discussion, which decreases the necessity to make notes.

L1D1 (Technical Overview). Interviews on the second A3AO revealed that the A3AO developed by closely following the A3AO cookbook gives *a good overview* of the charging system and is *very useful for training new employees*. The textual side helps for *easy navigation* throughout the A3AO, while the model side *triggers discussions* and is more to be used in daily work. During the research period, this A3AO has already been used for discussions and to get new employees up to speed as fast as possible.

The observations correspond with the survey held (Table 1). Survey respondents state that the A3AO gives a better overview compared to current documentation, is easy to navigate and to understand. The easy navigation was due to a combination of the textual description on the summary side, and the clear representation of the models on the model side. Using colors, icons and visuals consistently helped in easy navigation and understanding. Both the interviews and surveys showed that having multiple views on one page was considered a useful characteristic.

Since the A3AO contains specific parameters of the system, the respondents questioned the *effort it takes to keep it up-to-date*. Additionally, the A3AO covers one vehicle model, while there are multiple model lines that are developed simultaneously. This appeared difficult to capture in one overview.

L2D1 (Smart Charge Communication). The A3AO on smart charge communication is a much more dynamic A3AO. It is designed to trigger discussions to come up with a new improved functional partitioning. The researcher tried to actively apply this A3AO in a meeting with six engineers attending. The A3AO was sent to all participants beforehand to read. After the introduction of the A3AO, the focus of the meeting quickly shifted from the A3AO to the way they had been working before. Due to the complexity of the topic combined with the speed they continued, this A3AO was actively applied once.

Afterwards, interviews were held with three participants of the meeting. They stated that the A3AO gives a much *better overview compared to current documentation*. However, switching from current methods to new ones initially costs *additional effort, both in creating and using*. Therefore, they hesitated on switching to the A3AO while being in the middle of an ongoing and deadline-critical process.

In the interview and survey, the respondents stated that especially the *front side was useful*, while the benefit of the *backside was not always clear*. The colors and visuals used were considered neither useful nor useless according to the survey. From the interviews, it appeared they do help in understanding the topic, but also makes the dynamic A3AO ‘look nice’, which gives a feeling that it takes a lot of effort to construct it.

L2D2 (WPT Cybersecurity). The general response on L2D2 is comparable to the previous A3AOs. It gives a *good overview* of the topic at hand, especially due to the *multiple different topics* that are captured in one overview, as the survey shows as well. The survey also shows that the A3AO is *less easy to understand and navigate*. This corresponds with the feedback obtained during the interviews. The A3AO neither contains an explanatory textual side, nor clear visuals to support navigation throughout the A3AO. Nevertheless, with a small introduction to the A3AO, the A3AO was considered useful.

L2D3 (User Interface). For the last topic, only one respondent was able to fill in the survey. However, multiple people gave feedback on the A3AO. The physical overview showing *real pictures was considered simple but very useful*. Using these pictures again in smaller form for the partitioning was highly appreciated, since this made it easy to connect the partitioning with the physical overview. Furthermore, the improved overview of the A3AO compared to current documentation was considered one of the main positive aspects.

General observations

Several general observations were made throughout the process. These observations were related to different subjects and stored in the logbook. The main findings are presented below:

- The developed format, a *center box* with surrounding boxes to display topics in more detail, is a good way to display and communicate information of a system that deals with a variety of topics. The format combined with navigational tools and textual descriptions makes it easy to understand and navigate and therefore suitable for self-study.
- The A3AO developed according *the cookbook format* provides a good system overview, while still being able to display detailed information. It is a powerful tool to display multiple complementary views of a system within one overview and can be used both for self-study and in discussions.
- The A3AO showing *the partitioning of functions* has potential to be used in discussions. However, L2D1 also shows that applying the A3AO method for the first time in a highly dynamic and deadline-critical engineering environment might not always be beneficial.
- L2D2 showed that with less aids to guide the reader throughout the A3AO, it becomes harder to be read without any explanation beforehand. Whether this is an issue heavily depends on the goal of the A3AO.
- *Real pictures* help for easy and quick understanding, especially, when they are re-used consistently in other parts.

Feedback on the A3AO method in general

After discussing the specific A3AOs during implementation and in the final feedback session, the A3AO method was discussed in general. Seven statements on the A3AO method were given, as shown in Figure 12. In total fifteen stakeholders were interviewed and completed the survey. However, statement 2 and 3 were completed by fourteen stakeholders and the last statement was only filled in by five respondents. This difference is due to the fact that solely respondents who were part of the creation process were able to answer these statements.

The benefits of A3AOs became clear after discussing the format and showing the A3AOs to the interviewees. Figure 12 shows that it is regarded as *a good tool to understand system behavior* (NPS = 11), and gives a *better overview compared to current documentation* (NPS = 6). This was also confirmed in the interviews. Especially, combining *multiple aspects or views within one overview* is considered as main advantage of the method. Furthermore, it is a good tool to *share and communicate architectural knowledge* (NPS = 6).

The A3AO can be *used in discussions* (NPS = 7). However, it must be noted that two respondents were 'neutral' on this statement. Interviews and observations showed that within smaller groups (<5 people), a single A3AOs suffices and can aid in discussions significantly.

The tool proves useful to *train new employees* (NPS = 10), especially when the A3AO is easy to navigate. Altogether, these observations are confirmed by the fact that the majority of the interviewees strongly agreed on the statement of wanting to have an A3AO of their own topic (NPS = 12).

The last statement shows that according to the five survey respondents, the benefit of the A3AO is more than the effort it takes to construct an A3AO (NPS = 2). These survey respondents were part of constructing the A3AO, and therefore were able to more objectively answer this statement. In contrast, interviews and experiences with people who were not part of the creation process were very impressed by the A3AOs. They expected *significant effort to be required to construct* the A3AOs. This explained the reserved attitude when asking whether they were planning to create an A3AO themselves of their own topic.

Interviewees furthermore expected the *effort of updating* the A3AO to be a disadvantage of the method, since a small change in content can force to change the entire structure of the A3AO. Furthermore, by storing information in multiple places, e.g. on the A3AO and in other company documents, resulted in *concerns regarding consistency* of the information.

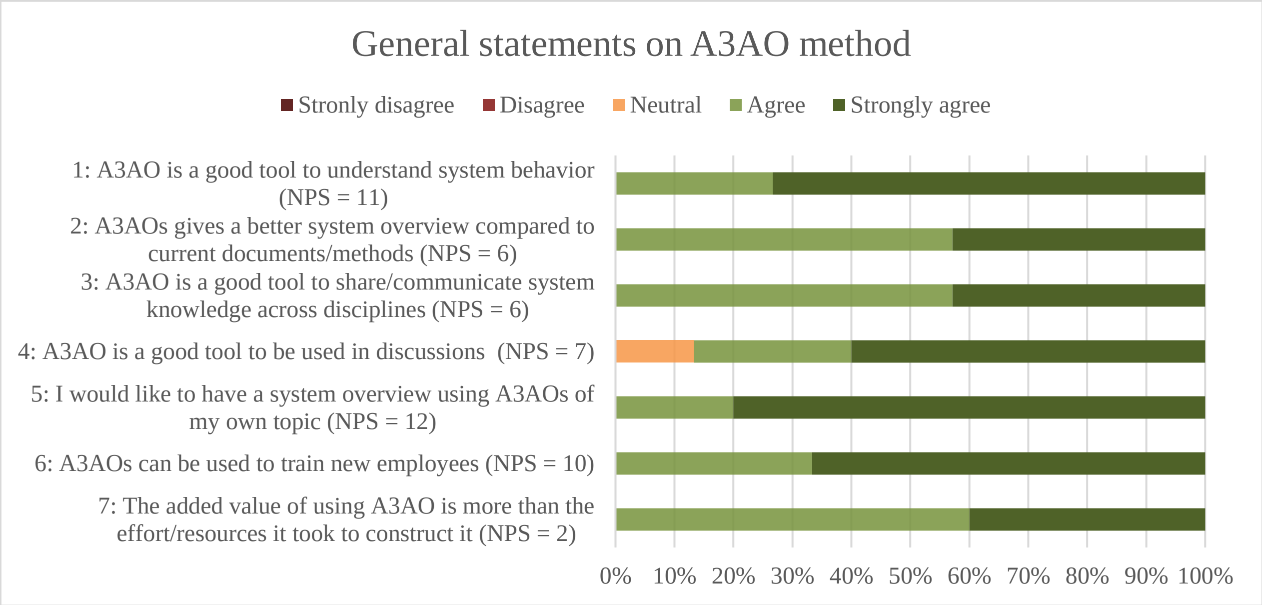

Figure 12: Survey results (including NPS) of statements on the A3AO method in general

Impact factors

The results above show that the A3AO method is a powerful tool to solve the current challenges. It showed its value in different topics, situations and levels of technical depth. Nevertheless, there are also concerns regarding effort to construct and update the A3AO, and regarding consistency. Therefore, results and experiences are combined into impact factors: factors that ensure the added value is maximized and the additional effort is minimized. The determined impact factors are divided into three parts. Firstly, the main general impact factors are discussed. Afterwards, impact factors relevant while constructing the A3AOs are discussed. Lastly, the impact factors relevant while using the A3AOs are discussed.

Main impact factors. *A3AO format:* During the creation of the five A3AOs, variations on the A3AO cookbook were made. In total three distinctive formats can be defined:

- The format created by Borches (L1D1), which is ideal for creating an overview of a dynamic and complex system. It has proven itself within multiple use cases, including the implementation within this research.
- The format to display a topic that deals with a variety of sub-topics (L0D1 & L2D2).
- The format to show the partitioning of functions (L2D1 & L2D3).

Each format proved to be useful depending on the information required to be displayed. However, creating a new format appeared to consume a lot of time. To keep the effort of creating an A3AO as low as possible, it is recommended to follow one of the predefined formats. Changes can always be made according to specific needs. However, experiences showed that a functional and physical view of the system helps in creating and communicating an overview of the system, and therefore should be included.

Implementation within existing development process: In addition to the effort of creating an A3AO, a big concern among employees is the effort it takes to update and maintain an A3AO. Furthermore, the A3AO needs to be accessible; it is not a tool intended to create once and store it just for documentation.
Especially, in a large and complex organization such as Mercedes-Benz R&D, with a variety of methods, tools and places to store information, this can be a challenge. After discussing these issues with several stakeholders, the hypothesis is that these issues can be tackled by *integrating the A3AO method into the existing development process*. For example, for each system an introduction has to be written at the beginning of a DOORS system specification. The A3AO could replace this introduction. This would reduce the amount of additional effort to construct an A3AO and updating the A3AO should therefore not require much additional effort.

During creation. *Goal:* Before creating an A3AO, it is important to set a clear goal for the impact of the A3AO. This includes problems aimed to be solved, as well as stakeholders to be addressed. A different goal of an A3AO can lead to an entirely different structure and content. For example, the goal of L2D1 (smart charging) was to aid within a dynamic process, which led to a structure with space to draw and make notes. The stakeholders were all experts, and, therefore, deep into the topic. The goal of L2D2 (cybersecurity) was to discuss the topic with suppliers, which have a different level of knowledge of the system, which lead to a more static A3AO.

Level of detail: During creation, the level of detail usually increases with each iteration. Experience showed that the more details are shown on an A3AO, the more people tend to focus and comment on those details. Adding details to the A3AO costs time. For more static A3AOs that take more time to design, more time can be spent on detailing. However, for more dynamic A3AOs with a shorter lifespan, detailing would cost too much time. Therefore, depending on the goal of the A3AO, it is up to the owner of the A3AO to decide the level of detail.

Navigational aids: Depending on the intended implementation of the A3AO, the A3AO should be self-explanatory to some extent. If, for example, the goal is to use it primarily within discussions, it is easier to explain the structure first. However, if it is required to read the A3AO beforehand, the A3AO should be easy to understand and navigate. To achieve easy navigation, several tools can be used such as graphical aids, numbering, colors and even text..

Consistency: For all elements used in creating an A3AO, it is important to stay consistent. This makes it easier for users to understand different A3AOs and to make links to other overviews created. This applies to e.g. structure, colors, shapes, terminology and visuals.

Challenge stakeholders: The intent of the A3AO is not to be complete, but to improve communication and trigger discussions, both throughout the creation process and after creation. Experience showed that by not showing complete or entirely correct information throughout the iteration process, stakeholders are triggered to participate in the discussion.

Finalizing the A3AO: Providing more details makes it more likely that people will comment on those details. Furthermore, every stakeholder has his own perception about what information is important. This can end up in a never-ending creation process. It is up to the owner of the A3AO to determine which information should be on the A3AO, and when the A3AO is finished.

During usage. *Group size:* An A3AO can be used in multiple ways. It can be emailed before a meeting to provide background information. Furthermore, it can be given to people who are not familiar with the topic, or it can be used as an artifact during meetings and discussions. While using an A3AO in a meeting, experience showed that it is a powerful tool when used in smaller groups.

Implementation time: Applying a new method initially requires additional effort. The predefined format and the fact that only standard tools (Visio/PowerPoint) are used to construct the A3AOs makes it an easy accessible tool. Nevertheless, it takes time for people to become familiar with the method. Experience showed that the more people became familiar with the tool, the more they saw the benefit of the tool. Therefore, it is important to take time to become acquainted with the A3AO method, and to gain experience in it. As a result, experience showed that applying the method in a deadline-critical ongoing process was difficult, since there was very little time to adopt to the method.

Discussion & Future Research

This research analyzed the implementation of A3 Architecture Overviews in the eDrive department at Mercedes-Benz R&D. Although, this is regarded as a representative case, it remains a case study. This, especially, holds for an engineering organization such as Mercedes-Benz R&D, where in different departments different cultures and way of working can consist. Nevertheless, within this research interaction with employees from different departments and even different continents took place. The response and observations among the different were comparable. Therefore, the general statements made within this research are expected to be valid within other dynamic and complex engineering environments.

This paper can be regarded as first attempt to create and implement A3AOs in such an environment, but time was limited to actively use the A3AOs on a larger scale. When similar research will be performed, more feedback on real usage and implementation of A3AOs can be obtained. Especially, implementing the tool within the current way of working is a topic of future research. Furthermore, in this research the researcher was the owner of each A3AO. However, as stated before, the information that is put on the A3AO is up to the owner of the A3AO. Therefore, it would be interesting to investigate the A3AO method when the employees create and apply A3AOs themselves.

The time of this research, six months on-site, was too short to evaluate the effect of A3AOs quantitatively. Therefore, current evaluation is done based on observations, experiences and feedback from employees. If this type of research would be done for a longer period of time, the effect of A3AOs could also be validated more quantitatively. For example, it could be evaluated whether the amount of change requests of a system decreases when applying A3AOs. Furthermore, the amount of feedback on the level 2 A3AOs was limited to three employees for L2D1 and L2D2 and one survey respondent for L2D3. However, considering the responsibilities of the employees, and the fact that in total 15 employees filled in the surveys, shows the appreciation of the research. Nevertheless, for more statistical analysis, the pool of employees giving feedback should be bigger.

Conclusion

The goal of this paper is to investigate to what extent A3 Architecture Overviews can aid the development process in a large, complex and dynamic engineering organization such as Mercedes-Benz R&D, and which factors affect this result. Current challenges were identified within communication of architectural knowledge, level of system knowledge, amount of system documentation, finding system information and training of new employees. Additionally, employees themselves were not all aware of these issues, or learned to live with them.

Besides the original A3AO format, two other formats were created and evaluated, leading to a total of five A3AOs. Based on observations, experiences and feedback of the five A3AOs, the A3AO method proves to be a good tool solve the observed issues. It gives a good system overview, assists in communication and is a documentation tool as well. It triggers discussions and is a good tool to train new employees. However, it also takes effort to create and maintain the A3AOs. Combined with the fact that employees are not aware of the issues, they initially hesitate on using A3AOs.

Impact factors that ensure that the added value of an A3AO is more than the effort to create and maintain it, are:

- Defining the structure. Developing a new format takes a lot of time, therefore, sticking to the predefined formats reduces the effort of creating.
- Reducing the effort of creating and maintaining A3AOs by implementing the method into the current development process.

When all impact factors are taken into account, the positive feedback and experiences result in the fact that the A3AO method can be regarded as valuable addition to the development process within a complex and dynamic engineering environment.

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Biography

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Wilco Pesselse studied Automotive Engineering at the Eindhoven University of Technology, the Netherlands. After his internship on hybrid powertrain modelling at the Sungkyunkwan University in Suwon, South-Korea, he started his graduation project at Mercedes-Benz. In 2018 he graduated and obtained his Master's degree in Automotive Technology. He is currently working at the Big Truck Development Center at Hyster-Yale as Engineering Trainee, being responsible for the Fuel Cell integration of the Electric Top Loader.

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