Shaping a GAIA-X Data Ecosystem through Innovation Modeling

Ali Shakeri, Oliver Klemp, Bernd Westphal
German Aerospace Center (DLR)
Institute of Systems Engineering for Future Mobility
Escherweg 2, 26129 Oldenburg, Germany
{ali.shakeri, oliver.klemp, bernd.westphal}@dlr.de

***Abstract*—The European GAIA-X project aims to create an innovative open, transparent and secure data infrastructure for different domains like energy, agriculture, and mobility. Data providers and consumers from one domain are supposed to form a data ecosystem on this infrastructure. Developing a new GAIA-X ecosystem for a particular domain is challenging because the participants of the ecosystems develop new business models and specifications of novel services while refining the requirements on the GAIA-X infrastructure, which is currently under construction. There is a need for approaches that help the consortium of participants in this innovation exploration task, i.e. to handle the complexity and provide communication means on a right level of abstraction. The Innovation Modeling Grid (IMoG) is an innovation modeling methodology with well-defined procedures that can help understand the GAIA-X problem space and present the model concisely. We applied IMoG as an innovation modeling approach on a GAIA-X ecosystem focused on mobility. In this paper, we present our experiences gained during this study. We found that using IMoG led to a better understanding of the roles, services, and interfaces in a specific GAIA-X ecosystem.**

***Index Terms*—GAIA-X, Innovation Modeling, Committee-focused Requirements Engineering**

I. Introduction

The GAIA-X initiative seeks to build an open, transparent, and secure data ecosystem based on European values. In this innovative data ecosystem, participants can offer or use so-called services to build data-based value chains. Participants are supposed to find each other through so-called federation services which rely on meta data of the services which may describe, e.g., data quality, legal conditions, and give a specification of the concrete interface to the service. With GAIA-X, challenges in data-based value chains such as under-specified interfaces between collaborators, unclear or ambiguous legal considerations on data exchange, and handling the complexity inside the structure of the value chain shall be solved.

These challenges with data-based value chains already surface today, for example in the automotive domain and more specifically in the life-cycle of upcoming automated driving functions: Scenario-based testing [1], [2] needs a simulation environment, map data of a certain quality, environment traffic models, or sensor models, which can all be seen as examples for services in a data ecosystem, even the scenario-based testing itself. Hence there is a demand to establish the GAIA-X data ecosystem as soon as possible.

The main open challenge to this end is that GAIA-X is intentionally specified rather vaguely to avoid over-constraining, e.g., meta data definitions since GAIA-X is supposed to support as diverse domains as mobility, energy, finance, and agriculture. On the other hand, the prospective services (like the example of map data mentioned above) are currently not yet existing as GAIA-X services but are individually negotiated between business partners. Other services may be part of innovative business models that are not economic without a reliable data ecosystem and hence their interfaces and the meta data to be managed by federation services are not yet well defined and it is hard to show-case them to prospective clients without a proper data ecosystem.

This "chicken and egg" situation is currently addressed by bringing together prospective service providers (who offer data services) and consumers (who use data services) from sufficiently coherent domains, as well as parties that work on refining and implementing the infrastructure to better understand the requirements and possibilities of GAIA-X and build the data ecosystem for different domains on the go. This domain-specific approach is expected to make it possible to explore the unique characteristics of each domain and design ecosystems that meet the particular needs.

Prospective producers, consumers, and infrastructure providers basically conduct a joint innovation exploration as a committee. While each party may have an internal creativity approach to come up with possible innovative data services, they come together for providers to get a rough idea of what consumers need, and for consumers to get to know the services that could be on offer. Infrastructure providers learn about how to adequately support these business models in the GAIA-X ecosystem. The exploration has limited time and needs to be conducted on an appropriate level of abstraction to leave room for implementation decisions.

Joint, committee-based innovation exploration, modeling, and roadmap development is a known requirements engineering problem in the automotive domain. The particularity of being a committee effort is that there is not one party who dominates decisions and is the sole origin of requirements but that different partners like different car manufacturers and suppliers aim to negotiate and agree on a common roadmap, e.g., for the development of sensor systems who support the next generation of automated driving functions. To this end, there is a need for a common modeling language to enable the parties to effectively discuss options, a process which keeps track of dependencies between artefacts, and a methodology which guides the exploration and modeling activity so to make it more predictable and to avoid getting lost in details.

In this paper, we present and discuss results and experiences from applying the innovation modeling approach IMoG [3], which has been designed for the automotive domain, to the exploration of prospective GAIA-X services for the product life-cycle of automated driving functions. The Innovation Modeling Grid (IMoG) is a requirements engineering approach for modeling innovations which consists of perspectives and abstraction levels to represent different views on the system. IMoG focuses on dividing the problem and solution space into suitable representations for modeling innovations. We have applied IMoG from the perspective of one particular partner in the committee for the (sub-)ecosystem for the considered domain. The consortium for this GAIA-X (sub-)ecosystem consists of several commercial companies and research institutes. The particular partner was the Institute for System Engineering for Future Mobility (DLR-SE), which operates under the German Aerospace Center (DLR). DLR-SE contributes to this GAIA-X ecosystem with exemplary verification services. These services play an essential role in the homologation of vehicles with automated driving functions through GAIA-X. The other committee members are car manufacturers, public transport data providers, sensor model providers, simulation providers, and infrastructure providers.

The paper is structured as follows. Section II presents the related work of innovation modeling within a committee. Section III briefly recaps the Innovation Modeling Grid (IMoG) used in this work. Section IV describes the problem of the mobility ecosystem considered here in detail. Section V presents the model that was created within the application of IMoG on this problem. Section VI describes the experience with the approach and Section VII concludes the application.

II. Related Work

The creation of innovations in general, from idea to product, is a broad topic that benefits in many ways from requirements engineering models, processes and methodologies at different stages. In this paper, we consider innovation exploration and modeling in the setting of a committee as outlined in the introduction and apply the methodology IMoG [3] to a particular innovation development in the context of a data ecosystem. In the following, we first discuss related approaches, most of which address different challenges or phases in the innovation process than IMoG. More details on the IMoG methodology, process, and modeling approach are provided in Section III. For the most closely related approaches, we discuss industrial evaluations and experience reports.

Innovations are implementations of new ideas or solutions. Approaches to the elicitation of new ideas and solutions include creativity techniques such as brainstorming [4], the six thinking hats [5], or mind mapping [6]. Such creativity techniques would be employed before or partially while working on the first perspective of IMoG. Creativity techniques alone give no guidance on how to refine the creative ideas, exploring their solution space, and communicating them properly in a committee. In the particular example of verification services in a data ecosystem, the innovation idea to work on was already available in a first approximation.

Innovation management techniques have been proposed to foster innovation inside corporations, where innovation management can be understood as the process of creating, implementing, and maintaining a culture of innovation within an organization. It involves the identification of new ideas, the development of strategies, and the ongoing evaluation of the success of those strategies. One example of a particular project management technique is the stage-gate process [7]. The main aim is to see only the most promising ideas developed further so to not waste resources on projects that are unlikely to succeed. There is a series of stages and gates that a project must pass through in order to proceed to the next phase. The flexible stage-gate process focuses on the development of products and the organisation where the product is developed and widely adopted by companies. It does not provide methodological guidance for committee-based innovation exploration and modeling, yet each organization with representatives in the committee could follow a state-gate approach internally and see the IMoG activities as an early stage.

Effective and efficient communication during innovation exploration needs adequate descriptions. IMoG follows a model-based approach and is basically agnostic to the particular modeling language that is used to describe steps in the exploration of the solution space. That is, it could employ general-purpose languages from UML [8] or SysML [9], as well as domain-specific architecture notions like Autosar [10]. For the exploration of the problem space, IMoG recommends a variant of feature models [11], [12], which are used to support decision-making and trade-off analysis. Feature models provide a notation of features and their relationships in a system and are excellent at capturing the user needs and the variety in the demands. Feature models are a powerful approach for managing complexity and facilitating communication among stakeholders, as they provide a clear and concise representation of the system's features and their dependencies.

A similar approach to modeling in the management of classical automotive system innovations is followed by Gleirschner et al. [13]. The focus of this work is a modeling approach that connects three different perspectives: the problem space, structural aspects of the solution space, and finally behavioural aspects of possible solutions to bridge the gap between ideas for innovations and their implementation. The first two perspectives are similar to IMoG, which does intentionally not include a behavioural perspective to keep the focus on the innovation exploration in the committee. Hence, IMoG would directly connect to [13] when it comes to the in-house implementation of the innovation. What IMoG adds over [13] on the process level are roles and activities that reflect the situation of largely independent partners in a committee who need to go back and forth between discussions in the committee and internal discussions of possible solutions within each organization. In addition, IMoG proposes a methodology on top of the process, which aims at guiding the committee members through the innovation exploration.

III. The Innovation Modeling Grid

The Innovation Modeling Grid (IMoG) methodology [3] is a requirements engineering approach for modeling innovations within a committee. Exploring and modeling innovations in a public committee differs from the typical requirement engineering problems in that the focus is not on detailed system designs incorporating numerous requirements. In contrast, the problem is to develop a representation of an innovation and its enablers or a set of related innovations on an appropriate level of abstraction so that the members of the committee can align their business decisions for a certain time horizon without violating compliance regulations.

IMoG follows a classical approach to distinguish between problem space and solution space, and proposes to analyse the spaces through so-called perspectives. The perspectives related to the problem space, such as the Strategy Perspective, the Functional Perspective, and partly the Quality Perspective, focus on describing aspects of the problem without technical details. On the other hand, the perspectives related to the solution space, such as the Structural Perspective, the Knowledge Perspective, and the latter part of the Quality Perspective, describe potential technical solutions corresponding to the problem in an abstract manner. IMoG considers these five perspectives on the following three abstraction levels. The *Context Level* which describes the innovation as a whole system embedded into its environment. In the automotive domain, for which IMoG has originally been developed, this level is typically in the interest of the OEM(s) in the committee. The *System Level* describes the innovation systems and their parts, and is in the classical automotive setting most relevant for Tier 1 suppliers. Finally, the *Component Level* describes the components of the system in its atoms.

The five perspectives and the orthogonal three levels of abstraction can be arranged into the matrix (or grid) shown in Figure 1 where perspectives are in the columns and abstraction levels in the rows. Each cell in the grid is basically a model of a particular aspect of the innovation under development. The artefacts and their dependencies in the grid form the IMoG process model together with the roles and activities (see Figure 2). The activities are understood here as activities of the committee. The committee consists of a committee leader, corporation representatives, IMoG experts, and optionally a roadmap manager. The corporation representatives will represent the interests and solutions of their in-house team, consisting of, e.g., a requirements engineer (at best also trained in IMoG), domain experts, system architects, and (if needed) an in-house roadmap manager. The upper half of Figure 2 illustrates how the involvement of roles is supposed to change over time. In the following subsections, we briefly describe each of the perspectives to be addressed by the given roles in the given activities. For more details on IMoG, we refer to [3].

A. Strategy Perspective

The Strategy Perspective usually starts with creative methods, discussions and sketches to find and create the idea of the innovation. The outcome is used for creating the innovation description of the Strategy Perspective. The description may contain the innovation strategies, a vision, rationales, sketches and goals. Additionally, the description may mark some elements as identifiable elements for referencing and tracing. The description and the identifiable elements build the basis for the modeling activities on the other perspectives.

B. Functional Perspective

The Functional Perspective describes the required features (end-user visible characteristics) and functions (traceable tasks or actions that a system shall perform) of the innovation. The metamodel of the Functional Perspective is based on the well-known feature models [11]. User Stories or Use Cases can be optionally added to the features and functions if the need for more information on each feature and function is identified.

C. Quality Perspective

The Quality Perspective contains the quality requirements and the constraints of each feature and function. As a means of representation of the Quality Perspective, requirement diagrams and requirement tables are suitable representations. The strategy description, the features and functions and the requirements and constraints build together the problem space. It is noted that the Quality Perspective also contains the quality requirements and constraints of the solution space, which are referenced on the solutions on the Structural Perspective.

D. Structural Perspective

The solutions are modeled on the Structural Perspective. The word “Structural” does not only refer to the relations between solution blocks but also the properties and values of these solution blocks. The context level of the Structural Perspective contains the environment and the relations and effects between the environment and the innovation. The system level involves decomposing the innovation into components, including the software and hardware elements. Software and hardware elements as well as architectures and mappings between them are included in the system level. The component level encompasses the system atoms which are decomposed from the system blocks. The atoms may include sensor descriptions with parameters, functions, properties or abstract technologies. For creating a solution space, any form of constraints and parameters of chosen technologies are particularly of interest. Furthermore, requirements can be added to any solution block on any abstraction level. These requirements are placed on the Quality Perspective and referenced on the corresponding solution blocks on the Structural Perspective.

E. Knowledge Perspective

The insights from the innovation as well as any reusable element, can be stored in a database for other innovation models. This database is called Knowledge Perspective. The

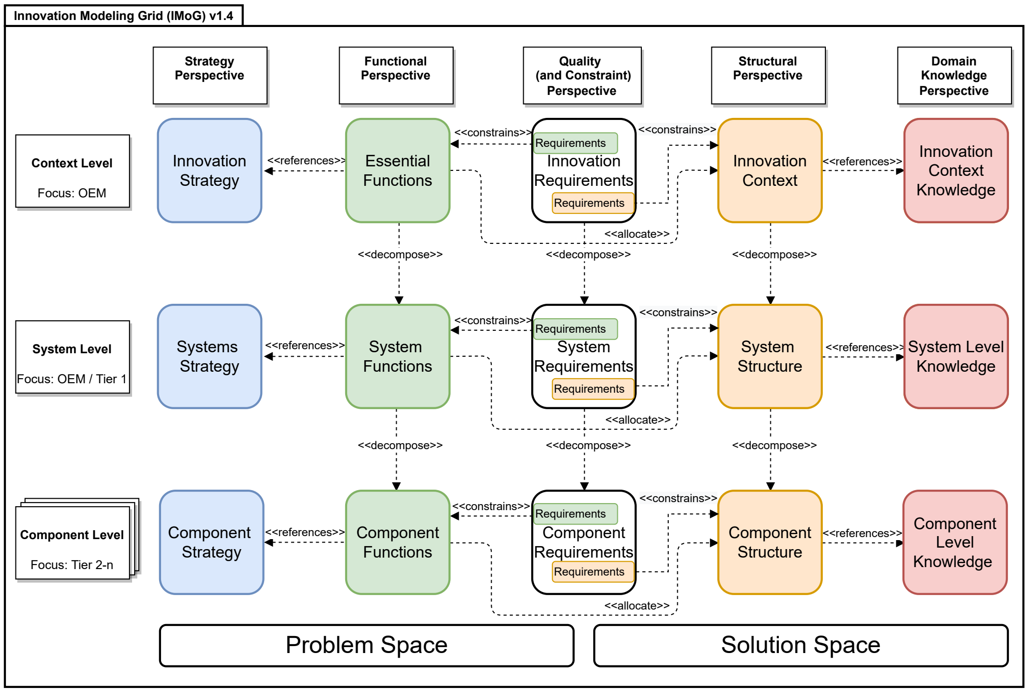

Fig. 1. The IMoG methodology [3]. IMoG consists of three abstraction levels (rows) and five perspectives (columns).

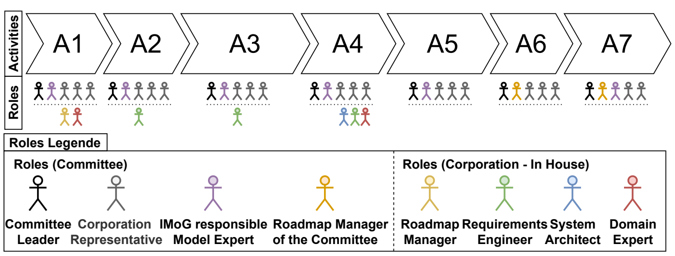

Fig. 2. Activities A1 to A7 and roles of the working process. Activities are (A1) Innovation Identification, (A2) Feature and Function Identification, (A3) Requirements Elicitation, (A4) Solution Space Exploration, (A5) Knowledge Consolidation, (A6) Roadmap Creation, and (A7) Innovation Model and Roadmap Maintenance.

elements of the component database and knowledge base allow future innovation models to reference the recently completed innovation model. As an example, the database may contain sensor characteristics and constraints from road traffic regulations and several properties depending on the context of innovation. The insights gained through modeling all perspectives can then be used to write the roadmap.

IV. GAIA-X PROBLEM STATEMENT

New data-oriented services demand more trust in data storage, security, and licensing policy than current cloud systems can provide [14], [15]. GAIA-X aims to create a federated open data infrastructure that satisfies European values such as data sovereignty, privacy, confidentiality, security, technology neutrality, interoperability, and interconnectivity [16], [17]. GAIA-X mitigates trust concerns by providing an infrastructure where stakeholders agree on a common set of guidelines, values, and standards. To achieve this objective, GAIA-X will consist of several ecosystems, each corresponding to a specific domain, including automotive, health, and agriculture. Each GAIA-X ecosystem represents a group of participants creating an economic community and conforming to GAIA-X requirements. These requirements focus on interoperability, portability, sovereignty, security and trust and are implemented through the so-called federated services, a layer between the GAIA-X infrastructure and the services [17]. A participant of a GAIA-X ecosystem takes either the role of a service provider, the role of a service consumer, or the role of a federator. Federators are responsible for the federation services containing the above-mentioned services, such as identity management and policy control or by striving to ease the interaction between the service provider and the service consumer.

The primary problem in designing such a GAIA-X ecosystem is that both, the architecture and the services, are still under development. The GAIA-X producing services and consuming services as well as the federation services are domain-specific, which makes it challenging to generalize and find proper requirements towards the architecture of the ecosystem. On the other hand, it is challenging to define the service producer's and service consumer's interfaces without knowing the architecture and its benefits.

Therefore, project families are funded to investigate different domains to solve this dilemma for each domain. In each domain, the project families have to identify their stakeholders and roles first to be able to define the interfaces of each provider service and consumer service and then give them to the architecture designers. As time is limited for the projects, the architectures have to be designed in an early project stage, so both services and architecture are basically designed at the same time. This parallel design is a challenge that is further amplified by the following challenges.

First, when creating a new GAIA-X ecosystem, the participants have to identify and specify their services and interfaces before passing their requirements to the architecture designers. With numerous participants involved, this identification and specification become challenging due to high synchronization effort. Furthermore, these participants have a wide range of services and requirements that need to be fulfilled by the ecosystem. Collecting these requirements requires considerable communication among service providers, consumers, and those who develop the corresponding GAIA-X infrastructure. The wide variety of interests and policies of the vast number of participants further amplifies this complexity.

Second, the information exchange between the service participants from different fields of expertise and the architecture designers contains a lot of ambiguity, which is a huge challenge. Having a common specification language among all participants is essential to manage this issue. Therefore, GAIA-X participants have to formally specify their needs and interfaces by describing technical aspects, contract obligations, and other policies. Finally, this common language needs to be concisely implemented by the developers of the data infrastructure to support the specification of the participant's services.

Finally, GAIA-X aims to address new demands that conventional ecosystems cannot conveniently tackle. This makes specifying the service interfaces even more challenging. For instance, within the automotive domain, there is a need to transfer (meta-)data for maps, sensor data, or access verification services in a trustworthy and convenient manner. GAIA-X shall help to deal with these new demands within an automotive ecosystem. Also, a GAIA-X ecosystem would allow new business models for service providers. For instance, an easily accessible and low-cost HD-Map could be consumed by other providers to reduce time to market of their services. Addressing such new business models covering new demands and not yet specified services induces a lot of uncertainty for the partners, representing a huge risk and challenge.

The context of this paper is a GAIA-X ecosystem with services for the life-cycle of automated driving functions, including a scenario-based verification service [18]. The ecosystem participants related to the verification service are shown in Figure 3. The Original Equipment Manufacturers (OEM) is the primary holder of verification interest in the ecosystem for their automated driving functions. The Simulation Provider offers simulation-based verification and validation to the OEM, and HDMap and Scenario Providers offer the required input for the simulation. The Verification Provider executes the verification task on simulation data and provides a verdict.

V. Innovation Model of GAIA-X 4 PLC AAD

This section reports the innovation exploration activities for the automotive verification service chain of Section IV.

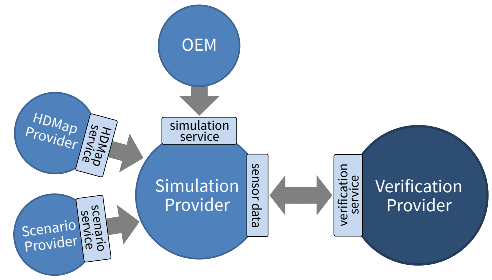

Fig. 3. The image depicts the main participants of the desired verification service for automated driving functions. Each blue circle represents one participant. The arrows depict communication directions, where the light blue boxes are the conceptual service interfaces. The research institute took over the role of the Verification Provider (dark blue circle).

The activities are presented from the perspective of one of the partners in the committee. This partner is an applied science research institute which contributes verification and validation services for automated driving functions to the data ecosystem. We decided to apply the IMoG methodology to gain a thorough internal understanding of these services and to effectively communicate with the partners in the committee without getting lost in details. IMoG represented a good fit to address the challenges mentioned in Section IV.

From the IMoG in-house roles (cf. Figure 2), we used the requirements engineer, system architect, and domain expert. The roles were assigned to three different people from the institute (the authors), a requirements engineer with IMoG expertise, a senior researcher as domain expert, and a researcher with more technical background as system architect. The role of roadmap manager was not explicitly assigned in the innovation exploration discussed here because the goal was not yet to develop a roadmap (in the sense of stages of extension or capabilities over time) but to identify the first stage. From the committee roles, we have different people in the role of corporation representative (cf. Section IV) including one person from the research institute. This person also took the role of IMoG responsible expert. In this case, it was sufficient to have a person who is trained in reading and explaining IMoG models since the focus was to represent the verification and validation service in the joint innovation exploration.

The IMoG methodology was applied by starting from the Strategy Perspective and then moving to the other perspectives from left to right (cf. Figure 1). Hence, we first discussed the problem space with the involved strategy, and functions and use cases on the Functional Perspective as well as the requirements and constraints on the Quality Perspective. Afterwards, we moved to the solution space by exploring the structure, variants and constraints on the Structural Perspective. As for the abstraction levels of the methodology (the rows of the grid), we decided to stay primarily between the context level and the system level, as the main focus was to understand the services of the research institute that were embedded in the GAIA-X ecosystem. Additionally, we could not further abstract the information level in our models because a few of our consortium partners required the modeling of this information. However, we did not strictly assign one abstraction level to the modeling elements as there is always an interpretation playground of where each element belongs.

The modeling activities started internally, in the institute, and the findings were then gradually brought to the attention of the committee. The IMoG methodology does not prescribe an order on in-house and committee level activities. In our experience, it was necessary and useful to invest a substantial amount of time on discussing the Strategy Perspective (cf. Figure 1). This was necessary because the in-house team needed to extend their data ecosystem expertise in general and their GAIA-X expertise in particular. We perceive this as specific to the particular innovation where the data ecosystem is under construction regarding both the business models and the details of the technical infrastructure. The effort spent turned out to be very useful because all following activities benefited (non-surprisingly) from a thorough understanding of the innovation idea and its context.

The modeling sessions for the IMoG methodology were spread over a period of six months and consisted of eight meetings for the Strategy Perspective, nine meetings for the Functional Perspective, one meeting for the Quality Perspective, and seven meetings for the Structural Perspective, varying in length from half an hour to three hours each. In addition, extra time was devoted for preparing these meetings and refining the models after each session.

A. Strategy Perspective

When starting the IMoG activities, the basic idea was already in place to start with including the Figure 3 (cf. Section IV). Hence there was no need to run any dedicated creativity techniques to identify the innovation idea. Yet we identified gaps in the understanding of the project with its goal to create a first GAIA-X ecosystem for services related to the life-cycle of automated driving functions. These gaps showed up not only internally but also on a project wide level. Internally and specific to the verification service considered here, we realized that some concepts related to verification or homologation of automated driving functions are still under active discussion in the overall research community. For example, the concept of "Operational Design Domains (ODD)" and the term "Scenario", which can specify the details of the simulation to run, can denote the data from a simulation run, and a specification of a requirement or a dynamic environment assumption (possibly as part of an ODD). Therefore, we first had to dedicate a good amount of time to the creation of a basic glossary that we added to the Strategy Perspective model. Such a glossary is also recommended in the IMoG methodology (as usual in requirements engineering). It needed to be created in this work while it may be directly available in other innovation explorations (at least one glossary per committee partner). This glossary helped not only us internally but proved to be tremendously useful in discussions of the project committee.

After refining our overall strategy, we put emphasis on improving our comprehension of the specific problem as defined by Section IV by a closer investigation of our strategy for the prospective verification service. We identified five essential verification services, which are required for verifying the safety of autonomous driving functionalities. Although other services could have been identified, they would have been of lesser interest to the consortium: Two offline verification services and three online verification services. Offline verification services represent situations where recorded data is uploaded for verification, while online verification services are understood as working on a stream of data. Online verification services are of high interest to the project since these demand more from the verification service ecosystem due to communication delay requirements. The diagram in Figure 4 summarizes the inputs and outputs of each service. These five services have been chosen to be representatives for different purposes (like ODD or specification checking) and for different kinds of data exchange (online vs. offline) and need to be discussed with the consumers in the ecosystem and with the technology providers, respectively. Although describing the inputs and outputs is not prescribed or recommended by IMoG as typical Strategy Perspective activities, we found it necessary to refine the strategy for the particular problem further. We offered this refined strategy and the identified verification services to the other participants. Once the verification services were discussed on committee level, we found no need to add other services to the list and no strong redundancy and concluded that we sufficiently understood our GAIA-X services. Thus, we considered the Strategy Perspective as completed.

B. Functional Perspective

Once the overall strategy had been outlined and understood, we switched to refining the problem space from the Functional Perspective. This perspective is represented in IMoG by the well known feature and function model, which are well-established for variant handling in the automotive industry [11]. The first step was the translation of the information gathered from the Strategy Perspective into features and functions. It turned out that we could directly reuse much details from Figure 4 as a baseline for our feature model. Creating the feature model may need a much higher effort in other applications of IMoG because there is no particular recommendation for the work on the Strategy Perspective in order to not constrain the creative work in this activity.

The verification service chain for autonomous functionality on the GAIA-X marketplace was selected as the root feature (see Figure 5). Then each of the five verification services from Figure 4 was added as corresponding features under the root feature. On this basis, it turned out to be hard for us to further refine and break down the features into sub-features, because we needed to understand the context of each feature better. Therefore, we followed IMoG's recommendation to analyze stakeholders, use cases and user stories.

We started investigating the different stakeholders of the verification services as well as the stakeholders of the whole verification service chain. We put ourselves in other project partner's view to understand and describe their business interests in the data ecosystem. These stakeholders were also

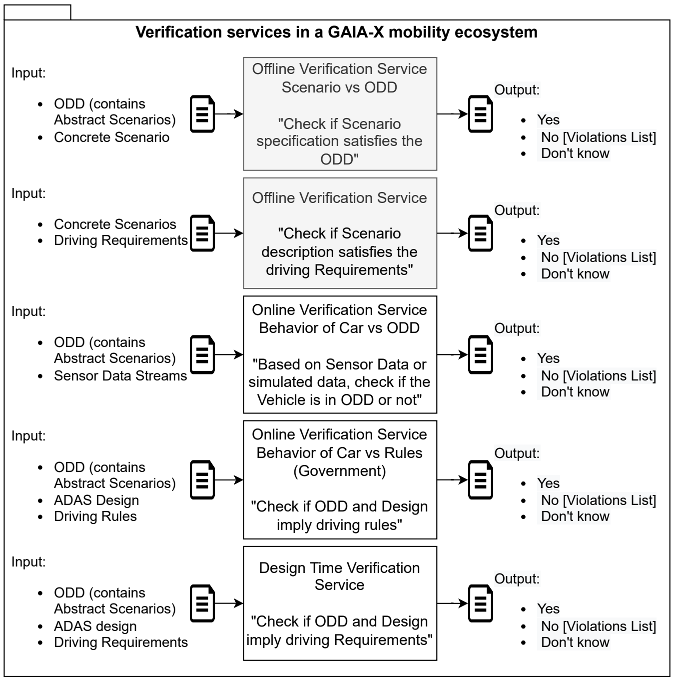

Fig. 4. The image depicts the proposed verification services (the outer box), with each service represented by its own box. The input and output lists of these services are represented by the "file" icon. In total, two offline verification services and three online verification services were identified. The offline services involve verification of the scenario descriptions based on Operational Design Domain (ODD) specifications, or driving requirements. The verification verdict is identified as output. The online verification services check whether real or simulated car data conforms to the specified ODD, whether the car's behavior violates the specified ODD, or whether the car's behavior violates driving requirements based on driving rules.

discussed with the project partners. Once we identified the stakeholders of the verification service chain, we created a sequence diagram and a use case to draft a typical process between those stakeholders. The stakeholder definitions and the sequence diagram enabled us to create user stories for each service feature of the feature model.

During the user stories creation, we identified two missing features: the validation service feature and the feature representing the interface to the GAIA-X ecosystem (in this case, also called marketplace). The first service was identified because the inputs of the other services have complex representations and therefore need to be validated first. The second service was identified after the creation of the user story, when we realized the need for a general interface for all services on the market. The investigation of stakeholders, sequence diagram, use case and user stories required several more meetings. We added the two missing features to the feature model and attached the stakeholder definition, sequence diagram, and use case to the root feature. After a few more meetings, appropriate descriptions with user stories were added to each feature.

Following IMoG, we investigated possible functions of each feature. Functions can be viewed as units that shall be implemented by the solutions, while features can be understood as end user visible characteristics. We did not decompose the five verification features into functions as it was sufficient for our purposes regarding the verification services and not important to know at that time by the committee. However, exploring the two new features in more detail was beneficial. Regarding the validation feature, we have different stakeholders in the committee that provide validation services. We required to decompose the validation feature into five specialized validation functions to distinguish the different services of the stakeholders and to avoid confusion. Regarding the interface feature, the interface to GAIA-X shall support online and offline modes that require a different infrastructure for data transfer. We added functions for each mode and added descriptions and user stories. We also added appropriate relations between the features and functions, including "requires" relations, mandatory relations labeled with "decompose" and alternatives and or-relations. Figure 5 shows the results.

We discussed our results with the project partners on the committee level, which was very welcome. Our pre-analysis of the ecosystem made it efficient to talk with the other partners about the verification services and the input-output relationships and functionality within the GAIA-X ecosystem because they just needed to understand and mainly confirm the results. In committees with less heterogeneous backgrounds of the partners, it may be possible to work on the committee level without such a thorough pre-analysis. In the project reported on here, it was however well-invested time. Our discussions did not uncover missing parts, so we concluded that the Functional Perspective model is finished.

C. Quality Perspective

With the features and functions identified and sufficiently described in the Functional Perspective, the IMoG methodology recommends to explore the quality of the features and functions as well as their constraints. These are typically requirements on the innovation that are considered to be necessary and assumptions that need to be satisfied to provide the features under exploration. Therefore, we added the quality requirements and constraints that were raised while creating the Strategy and Functional Perspective to the requirements table of the Quality Perspective. It is worth noting that these requirements represent the green requirements of Figure 1 that belong to the problem space. An excerpt of the requirements table (which contained 23 requirements at the end, including the requirements from the solution space) can be seen in Figure 6. These requirements and constraints primarily focused on the latency, throughput and execution of the online verification services. To avoid overlooking any requirements, we conducted a round of requirements elicitation afterwards. Due to the early stage and nature of the GAIA-X project (e.g. being about a digital service rather than an innovation with a physical aspect such as a new lidar sensor), only a few requirements were identified and added to the table. It is not uncommon with the IMoG methodology that requirements from the problem space are few at first and get extended during the exploration of the solution space, e.g., by requirements that ensure that unwanted disadvantages of technologies and solutions are avoided.

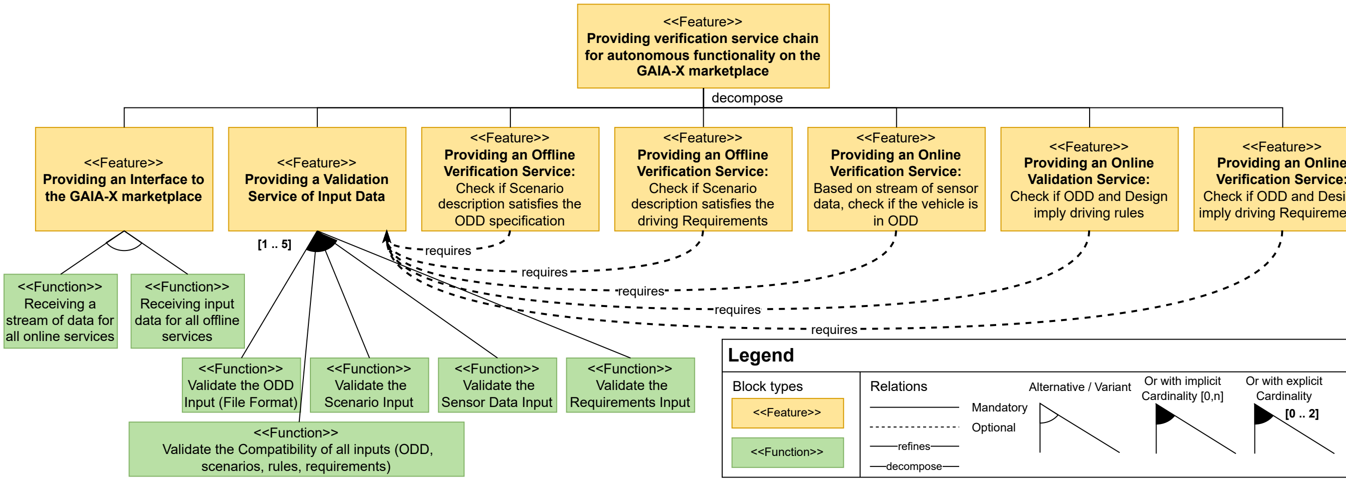

Fig. 5. The schematic view of the features and functions in the Functional Perspective. The model of the Functional Perspective can be considered a Feature Model that bases on the well-known work from [11] and [12].

We presented the requirements of the problem space to our project partners in the committee. Some committee members, particularly those interested in providing GAIA-X infrastructure, subsequently picked up the requirements because they were considered relevant for designing the infrastructure and marketplace.

D. Structural Perspective

Once the quality requirements and constraints were elicited on the Quality Perspective, the problem space was sufficiently covered and our attention moved to exploring the solution space with the Structural Perspective. Our main goal was to get a good understanding of the technical conditions under which the verification services can be provided. This includes the specification of the interfaces of our services (including the meta-data), the ecosystem's interfaces (e.g. how to provide the meta-data to federation services), the deployment of the implementation (cloud or on-premise), and the details of data exchange. To this end, we followed activities of two kinds: context level modeling and system level modeling.

We started with the context level, as we required the ecosystem's interfaces to shape our verification services. We proposed how the ecosystem would look like including the ideas we got from the project partners in the discussions along the innovation exploration so far. Recall from Section IV that the (sub-)ecosystem considered here consists of the GAIA-X marketplace (including the federation services), a Simulation Service Provider, an HDMap provider, a Scenario Provider, and our verification service. Our verification service – our innovation under exploration – was put in the ecosystem as a black box and set into relation (white-filled paths between blocks) to its environment (see Figure 7). Each block in Figure 7 has properties, including descriptions or their inputs and outputs, although these are not depicted in the figure for brevity. Variation of the blocks are also depicted by the variant stereotyped boxes next to the block (see, for example, the chosen variant "Integrated Services" for the innovation block).

The system level was investigated after the context level was sufficiently modeled. This level involved exploring the internal components of the innovation and identifying potential software and services that the system should provide. We decomposed the white service boxes and added software blocks describing their inner functionality. A particular focus was put on the verification service as it contained our functionality.

We presented our proposal to the project partners as part of our work. The proposal of the context was very valuable to the project partners as they wanted to know how they could interact with us and which decisions we took while shaping our services. With the feedback incorporated, we successfully finished the solution space exploration of our innovation.

E. Knowledge Perspective and Roadmap creation

Once we completed the Structural Perspective, we concluded that we do not want to spend effort to save the model elements in a database for potential future use that we hadn't planned for. Therefore, we decided to skip the Knowledge Perspective. Creating and maintaining a roadmap for us internally was also considered unnecessary, since the current expectation is that the ecosystem will evolve through market forces once the first ecosystem for this domain is available. That is, in this innovation exploration, the committee is first of all interested to reach one available ecosystem with a few, agreed on services rather than already discussing future stages. Therefore, we decided to skip the creation of a roadmap, yet if a roadmap would be considered useful in the future, the IMoG work could be picked up right here.

VI. Experience and Discussion

Overall, approaching the problem to develop the automotive GAIA-X ecosystem through innovation modeling was beneficial and addressed this type of innovation modeling problem within a committee adequately. This problem required a lot of communication and collaboration with the other participants of the (sub-)ecosystem under development and needed an

ID	Priority	Name	Text	Labels / Sources	Target	Abstraction Layer
1	1	Online Latency	The latency of GAIA-X service connection to the end user shall be sufficiently fast (less than 1 second).	Quality Requirement	Interface Feature	Component Level
2	1	Throughput	The upper limit on possible data transferred shall not be surpassed.	Constraint	Interface Feature	Component Level
3	1	Verification Logs	The verification logs shall be understandable for a normal user.	Quality Requirement	Verification Features	Component Level
4	2	Data Completeness	The sensor data transferred to the online services need to be complete (e.g. contain position data).	Quality Requirement	Interface Feature	System Level
5	2	Online Data Execution	The execution of the online verfication services have to be finished in a timely manner (tbd) so that the result can be sent back in time.	Quality Requirement	Verification Features	Component Level

Fig. 6. Part of the requirements table from the Quality Perspective. Requirement and constraint owns an id, priority, a name, a description, a type or source, a target reference to a feature, function or solution block on the Functional Perspective or Structural Perspective and an abstraction level for filtering purposes.

approach to shape the verification service and the whole (sub-)ecosystem, including proper interfaces in an efficient manner. From a time-investment perspective, IMoG made it easy to apply innovation modeling due to its well-defined process and methodology, which gave guidance and hence saved time in the planning of the next activities. Additionally (and well known in requirements engineering), having an IMoG expert guiding the involved members through the process, methodology and notation sped the activities significantly up because the GAIA-X domain expert and system architect could focus on the content instead of learning how to apply IMoG.

The decision to start IMoG in-house set the focus on the verification services and helped to uncover the need to re-consider the underlying concepts of scenario-based verification to put the verification service on solid grounds. This internal approach was very welcomed by the external committee partners, as many internal results were complementary to their work and the pre-analysis of the connection points sped up committee negotiations. Therefore, the recommendation for future modeling activities in comparably innovative and heterogeneous project situations is to appoint an IMoG expert, start the modeling activities in-house, and then join the collab-orative work with the committee in an iterative way, switching between joint committee work and distributed in-house work.

From a modeling activity perspective, IMoG provided a concise representation of the models. In particular, the well-known problem space and solution space distinction helped to reduce complexity in the thinking. To further elaborate on the modeling experience, the remaining part of this section focuses on the experience of each perspective.

On the Strategy Perspective, the initial understanding of the problem and of the service strategy was found to be too superficial so that an understanding of the verification services needed to be established. With IMoG, the internal strategy was then effectively shaped and IMoG models supported effective communication, both internally and externally. That noted, the strategy shaping took longer than expected. Future innovations inside GAIA-X or inside more established, classical domains (like automotive sensor systems) will be able to benefit, e.g., from existing glossaries. However, the overall time investment was considered worthy enough for the problem addressed here.

On the Functional Perspective, the identification of stake-holders, the creation of a use case, a sequence diagram and user stories were required and recommended by IMoG to further decompose the services. This also took effort and time; however, it supported us in understanding the problem and the services efficiently. Therefore, the investigation was considered well invested.

On the Quality Perspective, the investment focused on adding requirements and constraints to the feature. This effort took only two sessions and was finished efficiently. As already expected, not many requirements and constraints were elicited due to having no underlying GAIA-X ecosystem implementa-tion restricting the problem space. Thus, the IMoG approach of activity was also considered successful.

On the Structural Perspective, a fair share of time was invested to explore the solutions. This solution exploration was hard at the beginning, because of a lack of information about how the other partners approach their problems. By focusing on the whole verification service chain and treating the verification services as a black box, a proposal of an ecosystem design was made from the perspective of the service provider. This also tremulously helped the committee, because it enabled the committee to talk specifically about service interfaces. Overall, a better understanding of how to approach the services, what to do, how to collaborate with other committee partners and what potential relationships and interfaces exist between partners were identified. Afterwards, the verification services were investigated, which helped us, to understand the further implementation steps in the project. Also, IMoG efficiently supported this solution space explo-ration with its well-defined process and notation.

The Knowledge Perspective and the roadmapping were skipped internally, because we did not want to plan for the whole committee alone. This decision was considered appro-priate and increased our collaboration with the committee.

The addressed abstraction levels (the rows in the IMoG grid) were determined by the problem context: The GAIA-X concept in general (which is supposed to support many different ecosystems) represents the context level, and the ecosystem for the life-cycle of automated driving functions is the system to be analyzed. The (sub-)components of the verification service have not been analyzed further with IMoG since there was no need in the committee. Reconsidering the IMoG rows during the innovation exploration and modeling helped to not get lost in details at this stage of the modeling.

Overall, we consider the application of the IMoG method-ology, process, and modeling approach to the problem of shaping a particular GAIA-X (sub-)ecosystem successful, both in-house and in the committee. Figuratively spoken, the basic

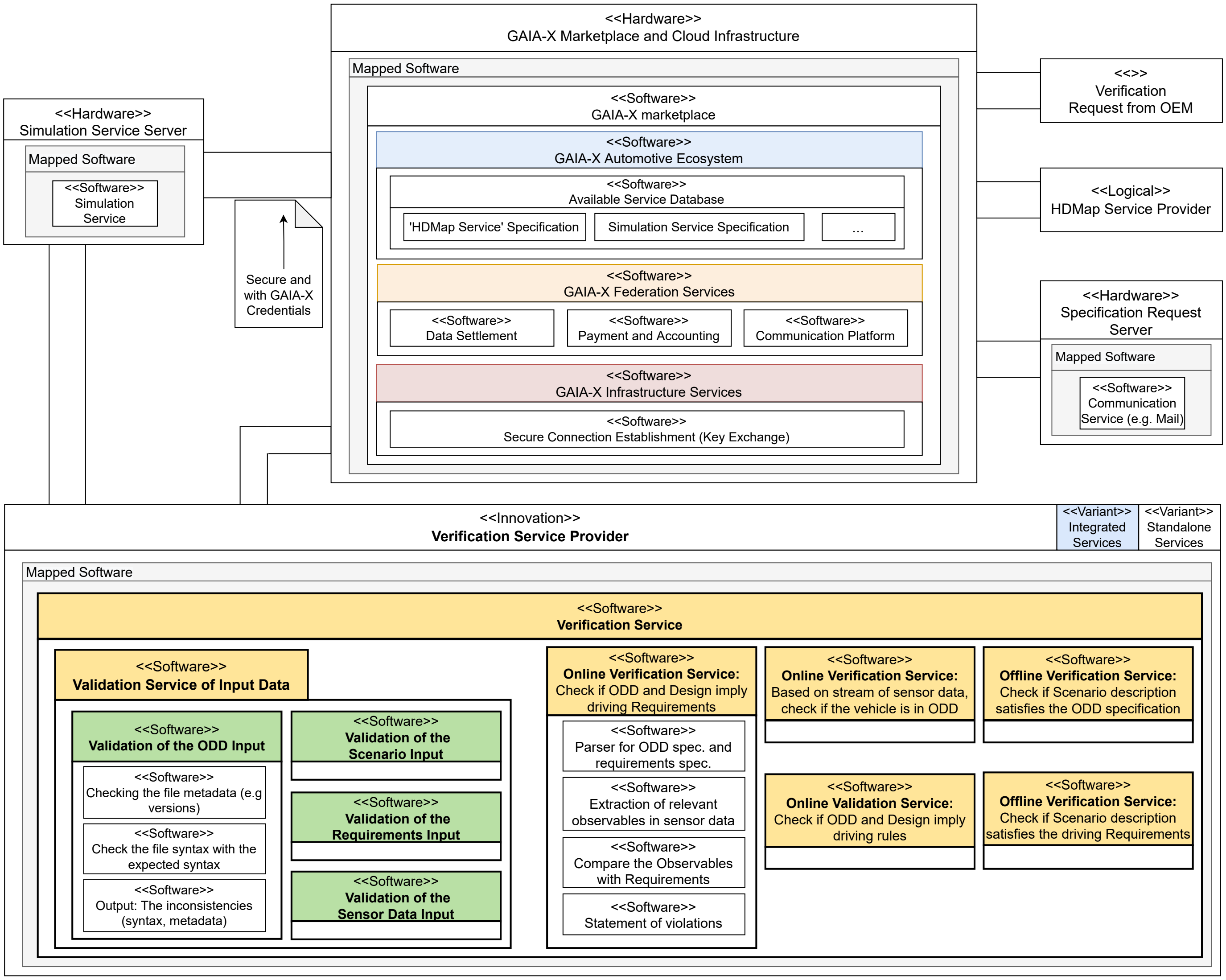

Fig. 7. The context level of the Structural Perspective includes the innovation (represented by a blue block) and its environment (represented by white blocks). The relations are depicted by white filled paths and the variants are represented by the boxes next to the blocks.

idea as illustrated by a collection of “blue circles” in Figure 3 has become a structural model (cf. Figure 7) that is now implemented into a solution. Committee work provides sufficient confidence that the solution will be useful to participants of this data ecosystem by the service it provides and by the interfaces through which it connects to the other services.

VII. Conclusion

In this paper, the IMoG methodology was applied to shape an automotive GAIA-X ecosystem focusing on providing a verification service chain. The IMoG approach and application were presented and the experience with each perspective of IMoG was discussed. The problem space contained the strategy, stakeholders, user stories, functions and constraints while the solution space exploration focused on the structure, interfaces and properties of the services. Overall, the application of IMoG to this problem of innovation modeling within a committee was convincing. The GAIA-X project profited from IMoG and further steps in the project were identified. The next step in GAIA-X is the creation of a demonstrator of the marketplace and the implementation of services that run on the marketplace. In addition, we support another application of IMoG in an automotive consortium to boost innovation across the whole value chain. Therefore, we recommend the use of IMoG for similar problems.

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