MOBILITY & VEHICLE MECHANICS

https://doi.org/10.24874/mvm.2023.49.02.01
UDC: 629.1;34.06

MBSE APPROACH FOR FACILITATING THE APPLICATION OF STANDARDS IN THE VEHICLE DEVELOPMENT PROCESS

Elena Angeleska [1], Vasko Changoski [2], Tashko Rizov[3], Sofija Sidorenko[4]*

Received in August 2022 *Revised in September 2022* *Accepted in October 2022*

RESEARCH ARTICLE

ABSTRACT: The development of complex vehicle systems that integrate latest trends and user needs with regulations, standards, and engineering requirements needs to rely on a strong multi-disciplinary collaboration between experts who exchange information from all relevant fields included in the vehicle development process. Constantly following, updating and applying the input information from various sources when working on vehicle systems can be a daunting task. The Model-Based Systems Engineering (MBSE) approach can provide a strategy for easier coping with the complexity of vehicle systems. This is extremely beneficial since it helps to create an information base where the information is represented in an integrated and consistent system model rather than in isolated documents. This paper presents a concept of an information platform based on MBSE. The goal of the platform is to become an engineering tool for incorporating all relevant data (requirements, standards, regulations) in a manner that they can be directly linked to the adequate system components, simple to interpret and be used by all members of the development team. The purpose of this platform is to: (1) facilitate the development process and interdisciplinary collaboration; (2) help to follow regulations correctly and avoid mistakes; and (3) keep all project data systematized.

KEY WORDS: *Vehicle Design, Platform, MBSE, Regulations*

[1]*Elena Angeleska, Ss Cyril and Methodius University in Skopje, Faculty of Mechanical Engineering, Republic of North Macedonia, elena.angeleska@mf.edu.mk,* https://orcid.org/0000-0002-6949-8391, *(*Corresponding author)*
[2]*Vasko Changoski, Ss Cyril and Methodius University in Skopje, Faculty of Mechanical Engineering, Republic of North Macedonia, vasko.changoski@mf.edu.mk,* https://orcid.org/0000-0001-6148-9389
[3] *Tashko Rizov, Ss Cyril and Methodius University in Skopje, Faculty of Mechanical Engineering, Republic of North Macedonia, tashko.rizov@mf.edu.mk,* https://orcid.org/0000-0001-7365-2446
[4] *Sofija Sidorenko, Ss Cyril and Methodius University in Skopje, Faculty of Mechanical Engineering, Republic of North Macedonia, sofija.sidorenko@mf.edu.mk,* https://orcid.org/0000-0003-2481-5557

MBSE PRISTUP ZA OLAKŠANU PRIMENU STANDARDA U PROCESU RAZVOJA VOZILA

REZIME: Razvoj složenih sistema vozila koji integrišu najnovije trendove i potrebe korisnika sa propisima, standardima i inženjerskim zahtevima treba da se oslanja na jaku multidisciplinarnu saradnju između stručnjaka koji razmenjuju informacije iz svih relevantnih oblasti uključenih u proces razvoja vozila. Stalno praćenje, ažuriranje i primena ulaznih informacija iz različitih izvora prilikom rada na sistemima vozila može biti složen zadatak. Pristup inženjeringa sistema zasnovanog na modelu (MBSE) može da obezbedi strategiju za lakše suočavanje sa složenošću sistema vozila. Ovo je izuzetno korisno, jer pomaže u stvaranju informacione platforme u kojoj su informacije predstavljene u integrisanom i konzistentnom modelu sistema, a ne u izolovanim dokumentima. Ovaj rad predstavlja koncept informacione platforme zasnovane na MBSE. Cilj platforme je da postane inženjerski alat za primenu svih relevantnih podataka (zahteva, standarda, propisa) na način da se mogu direktno povezati sa adekvatnim komponentama sistema, jednostavni za interpretaciju i koristiti ih svi članovi razvoja. tim. Svrha ove platforme je da: (1) olakša proces razvoja i interdisciplinarnu saradnju; (2) pomogne u pravilnom poštovanju propisa i izbegavanju grešaka; i (3) sve podatke o projektu čuva sistematizovano.

KLJUČNE REČI: *projektovanje vozila, platforma, MBSE, regulativa*

MBSE APPROACH FOR FACILITATING THE APPLICATION OF STANDARDS IN THE VEHICLE DEVELOPMENT PROCESS

Elena Angeleska, Vasko Changoski, Tashko Rizov, Sofija Sidorenko

INTRODUCTION

Today’s vehicles are complex systems consisted of not only the essential mechanical components, but also an increasing amount of electrical, electronic and software components, as well as features based on latest technological advancements, aiming to be more safe, smart, convenient, reliable, and environmentally-friendly. Vehicle developers are aiming to offer all these qualities in new vehicle models to respond to the ever-changing user needs and gain market advantage. Moreover, to achieve those goals, companies have also been moving the emphasis from just engineering, technology and manufacture aspects, to an understanding of how the products are perceived by users and how they interact with them to provide user-centered design solutions which are likely to be safer and more desirable [1]. As author Tumminelli states, todays vehicles represent much more than means of transport, they are link between people and places, they reflect current trends, they define the appearance of urban environments and the way of life [2].

However, the freedom of following human-centric principles, new technologies and trends is extremely limited and must be handled carefully because in the same time vehicle manufacturers are under the increasing pressure to meet the strict regulatory requirements regarding safety and environment preservation. They are required to follow specific regulations for the design of components, their manufacturing and placement, reuse and recycling, reducing emissions, improving fuel economy and the overall efficiency. This does not only impose limitations in the design and development process, but can be difficult to follow by all team members. All input information strongly influences the design of nearly all vehicle interior and exterior elements and should be considered from the earliest planning stages and be included in all phases of the development process of a new vehicle.

If we take a look at tasks that are part of the vehicle development phases (from product planning and assumptions, to finalizing the main project), it is clear that all of them require a combination of information inputs from a number of disciplines and sources:

•defining the main vehicle characteristics depends on market analysis and characteristics of the customer population (which also includes gathering anthropometric data and transferring customer needs to engineering specifications using methods such as the quality function deployment tool, QFD);

- regulations (such as those by The United Nations Economic Commission for Europe, UN/ECE) are followed in the development of all exterior and interior components;
- national road safety regulations are used for defining multiple dimensions, masses, performances and characteristics of the vehicles;
- standards (such as SAE J-standards by the International Society of Automotive Engineers) help to safely position the occupants, define their envelopes, reach zones and filed of view;
- directives (such as the directive 2000/53/EC on end-of-life-vehicles [3]) dictate the material choice for all components, etc.

The new vehicle development process, all its main phases and tasks are shown on the block diagram below (Figure 1). The diagram is generated based on literature review from authors Bhise, Macey and Wardle, and Danev [4], [5], [6] and shows how the requirements (input information from different fields) guide all the development tasks in all phases.

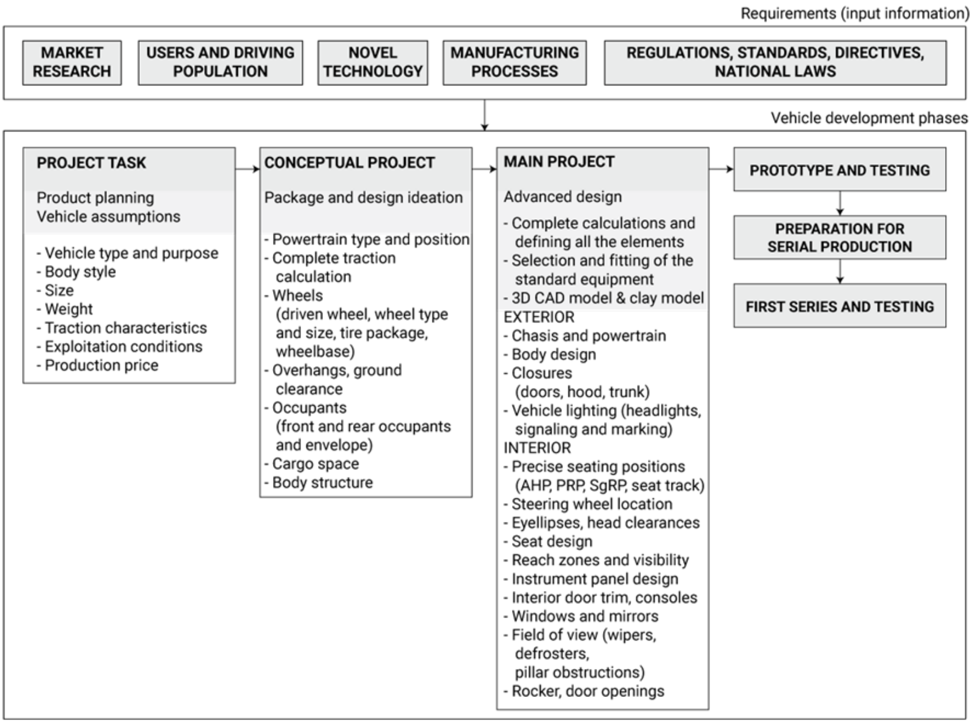

Figure 1. Vehicle development process – phases, tasks, and input information (requirements)

The diagram is a simple representation of how the vehicle design and development process is a daunting task which includes the use of a wide range of multi-disciplinary information and is under the influence of strict regulations. Therefore, there is a need for an assisting tool to support the development tasks. In this paper, such a tool is proposed in the form of a concept for an information management platform based on Model-Based Systems Engineering methods which were applied to offer a solution for systematizing the information, facilitating their use and reducing the risk of making mistakes.

1. REQUIREMENTS IN THE VEHICLE DEVELOPMENT PROCESS

As elaborated in the introduction, there are multiple sources of information that are included in the vehicle development process. The most crucial task is to gather all detailed requirements to be met in order to obtain vehicle approval, as well as requirements related to occupant safety and environmental preservation, and include them during the development of all vehicle systems and components.

For example, if we take the vehicle interior as a separate subsystem of the whole vehicle, there are specific regulations which refer to vehicle interiors and the components they are equipped with. The main UN/ECE interior regulations are Regulation No. 21 and No.17.

Regulation No. 21 of the Economic Commission for Europe of the United Nations (UN/ECE) — titled „Uniform provisions concerning the approval of vehicles with regard to their interior fittings“ [7], includes requirements for: placement of parts in the reference zone; parts of the control panel above the level of the panel; design and manufacture of contact control handles, levers, buttons and all other projecting objects; design of projecting parts of the roof; seat energy dissipation in the head impact zone; control of switches and safety devices; etc.

Regulation No. 17 of the Economic Commission for Europe of the United Nations (UN/ECE) — titled „Uniform provisions concerning the approval of vehicles with regard to the seats, their anchorages and any head restraints“ [8], includes requirements for: locking systems, adjustment and displacement systems for seats; design and surface characteristics of the rear parts of the seats; seat frame and seat attachment to prevent failure; installation of head restraints; seat backrest location; etc.

Moreover, special regulations are given for different types of interiors. For example, the regulation for interiors of M2 and M3 category vehicles is Regulation No. 107 of the Economic Commission for Europe of the United Nations (UN/ECE) — titled „Uniform provisions concerning the approval of category M2 or M3 vehicles with regard to their general construction“ [9], among other information, includes rules (with sketches) regarding: determination of unobstructed access to doors; width of passenger seats; permitted intrusion at shoulder height, in lower part of passenger space, above the seat; seat-cushion depth and height; space for feet of seated passengers behind a seat or at a seat facing the gangway; seat spacing; space for seated passengers behind a partition or other rigid structure other than a seat; etc.

In addition, standards for vehicle interiors help generate safe and ergonomic interior solutions. The largest base of vehicle development standards are the J – standards of the International Society of Automotive Engineers, SAE. One segment of these standards provide support for the design of vehicle interiors: SAE J826 defines and measures the H-point (estimate hip point of occupant in a seat) which is the primary reference point for occupant accommodation; SAE J287 defines a method for calculating the reach zones; SAE J941 suggests a method to define the drivers eye locations (eyellipse); SAE J1052 defines the head position contours; etc. [4], [10].

The main regulations and standards that need to be studied before beginning the design of interiors and choosing the components with which they need to be equipped are illustrated on Figure 2. The illustration visually demonstrates how all the components of the subsystem „vehicle interior“ are under the influence of specific rules and how the rules and requirements from different sources overlap in certain aspects.

Each subsystem of the vehicle is under the influence of multiple rules that need to be followed. The rules for vehicle interiors can also contain data concerning some other subsystems of the vehicle and their components (exterior). In addition, documents concerning the exterior subsystem can also have an influence on some aspects of the vehicle interior and its features. For example, the national road safety regulations contain information regarding permitted vehicle dimensions which also need to be considered in the interior development. The vehicle interior is elaborated as an example, but the same applies to all other vehicle subsystems.

Therefore, in order to successfully systematize and manage the information, a precise definition of the vehicle systems, subsystems and elements is needed. This can be done using Systems Engineering techniques (as explained in Chapter 3). By conducting a system analysis, all the input rules and requirements can be assigned to the correct vehicle subsystems on which different teams are working, avoiding possible omitting of important data.:

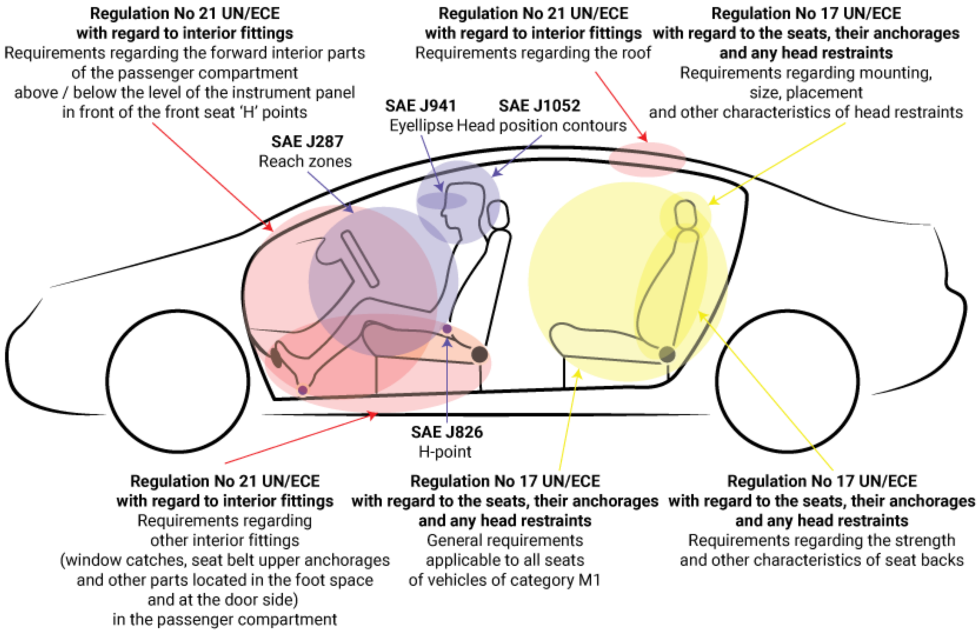

Figure 2. Main regulations and standards followed in the vehicle interior design process

2. VEHICLE SYSTEM ANALYSIS

One product (system) is composed of a set of interrelated components which work together to achieve the main purpose of the product (system). When complex systems are being developed, dividing them into smaller units (subsystems) helps to simplify the process of allocating the requirements and proceed with analysing the systems and defining their functions [11]. This is done by viewing the system as a whole and then breaking it down into components which are studied separately (Systems Engineering). This is also referred to as system modularity – complex systems are divided into modules at different levels which are „tightly coupled within, and loosely connected to the rest of the system“, which are actually complex systems themselves [12].

For the purpose of this study, the product „vehicle“ is analysed as a complex, dynamic system of systems. In order to propose a suitable method for easier monitoring of the defined requirements needed for developing this complex system (through an information management platform), an overview of the main vehicle groups of systems and subsystems was needed. Branching out the main system in order to compose the vehicle system hierarchy is the initial step in generating the model of the system which can be used as a base for systematizing the input requirements (standards, regulations, etc.).

Based on a literature review [5], [13], [14], the main subsystems of the vehicle were identified as: powertrain, wheels and tires, suspension and chassis, body, interior, electrical system, and electronic system. These main subsystems are composed of their own subsystems at different levels, which in the end, contain single elements. Further branching out of the level 1 subsystems was done in order to create a realistic representation of the basic vehicle hierarchy. This was done without great detailing due to the conceptual nature of the information management platform which is proposed in this paper. The identified subsystems and levels 2, 3 and 4 of the subsystems at level 1 are illustrated on the block diagram below (Figure 3).

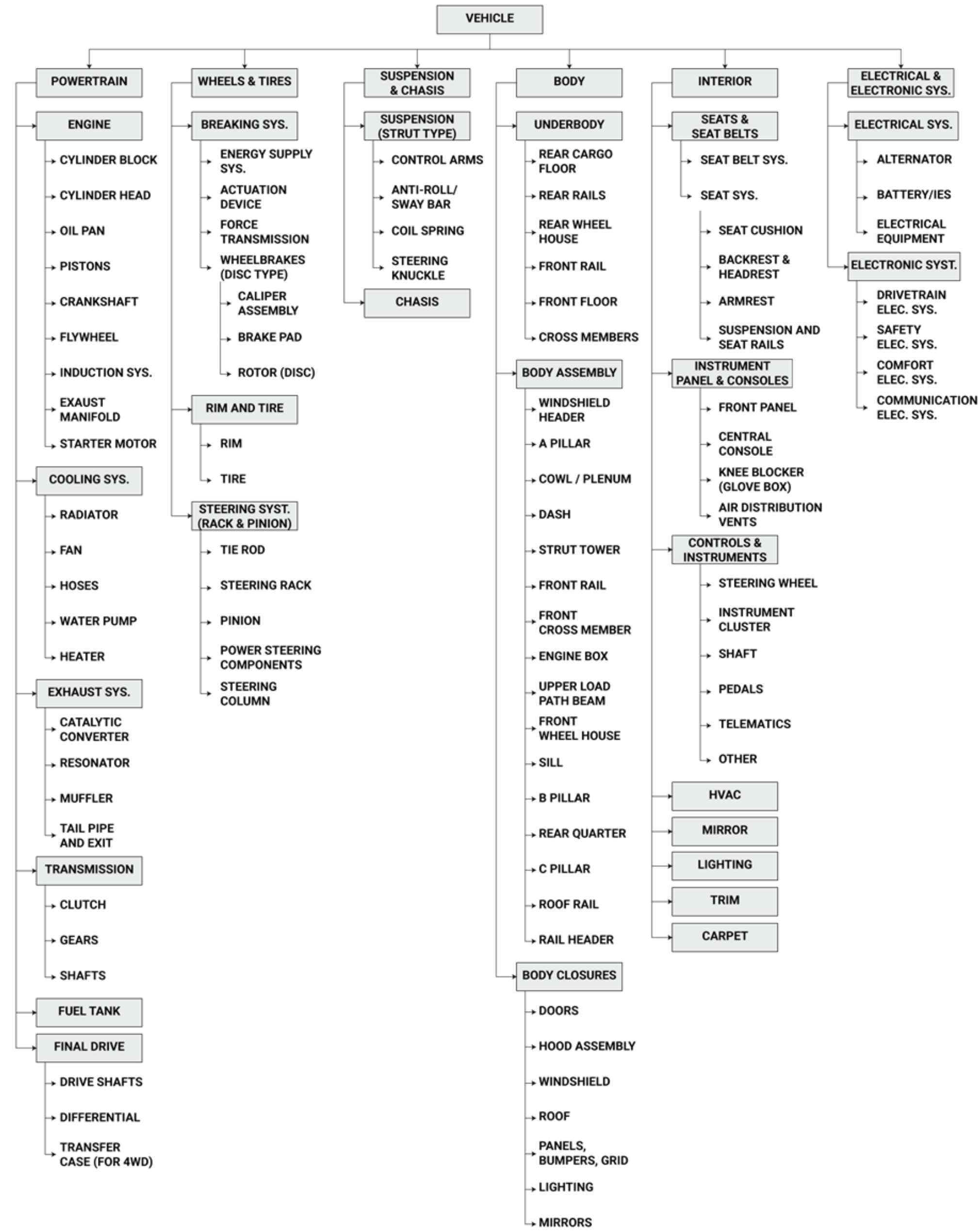

Figure 3. Basic hierarchy of the vehicle system

3. INFORMATION MANAGEMENT PLATFORM (MBSE APPROACH)

Model-Based Systems Engineering is a suitable approach for dealing with the challenges of modular systems (system of systems). The benefit of using Model-Based Systems Engineering models is the integrated representation of the information in four main domains of the consistent system model: requirements, behaviour, architecture, validation, which is a better solution than representing the information in separate documents [15], [16]. Such models are used for interdisciplinary product development [17], and to achieve product standardization, such as modular, platform or type series design [15]. System modelling languages (such as SysML) are commonly used to aid the creation of model-based representation of systems. Typically, models are generated by: firstly, constructing a product functional decomposition (functional model represented by functional flow block diagrams) where the goals are expressed as system functions; secondly, the functional model leads to a creation of a logical system hierarchy that defines the concept solution; then, the internal functional and logical architecture is described; and finally, relationships (allocations) are established which serve the purpose to link requirements with the functional and logical architecture [17]. Commercial software for vehicle system design based on these principles are available as product lifestyle management (PLM) cloud-based tools helping to manage requirements, product data and various product processes (for example: https://www.plm.automation.siemens.com/global/en/products/teamcenter). Model-Based Systems Engineering is a crucial part of these tools that commonly use function models (or standardized hierarchical functions) to generate functional design solutions [18].

However, the described approach requires an in-depth understanding of all systems and subsystems functions, components that can satisfy those functions, and their allocations and behaviours, which is not entirely possible at the early, preparation stages. It is often difficult to translate the given requirements into specific functions to be achieved.

When new vehicle models are being developed, multiple teams are assigned to work on different subsystems of the vehicle. Those teams are consisted of many members from various fields of expertise – managers, mechanical engineers, electrical engineers, industrial designers, etc. In order to facilitate the development process and avoid mistakes, all team members need to have access to the requirements they ought to use in the concept development of their assigned subsystem. This can be done only by presenting the requirements in an understandable manner for all members who need to easily review and select the required data.

Here we suggest a concept for an information management platform for easier application of requirements in the vehicle design and development process. The concept is based on Model-Based Systems Engineering methods, but on a more abstract level, suitable to be used as an assisting tool by all members of the research and development team. The requirements (primarily mandatory requirements such as standards, regulations, directives) are saved in a large information database. Each requirement is assigned a name, unique code, link to the document (which can be easily updated when needed) and keywords which describe what the requirement referrers to. The vehicle subsystems at different levels are saved in a different database. Each subsystem is assigned a name, unique code, and a code of its parent (or subsystem at a higher level that it belongs to). The hierarchical representation (which is actually the BOM list of the product) and individual codes and parent codes provide a simplified view of the main system and a possibility for a simple addition of new subsystems at different levels. The connection between the requirements and the subsystems is made using the codes of the requirements and codes of the subsystems. One requirement can be assigned to one or more subsystems, and one subsystem can contain information from one or more requirements. The concept for the information management platform is given on the class diagram on Figure 4.

The idea for the practical application of the platform is illustrated on Figure 5. The user (member from the development team working on an assigned subsystem) reviews the information database where the requirements are stored. After selecting specific data, the user selects the adequate subsystem from the system hierarchy and inputs the selected requirements by defining them as subsystem characteristics (width, length, mass, performance, etc.) and specifications for those characteristics (specific dimensions, distances, weight, energy consumption, etc.). This type of systematized representation of the requirements is stored in a tabular format and made available through the platform to all team members who can review, edit and insert new data. The final step is using the defined specifications for generating the systems morphological matrix where different options for the subsystems which satisfy the defined specifications are explored. Combining the different options results with various subsystem and system concepts.

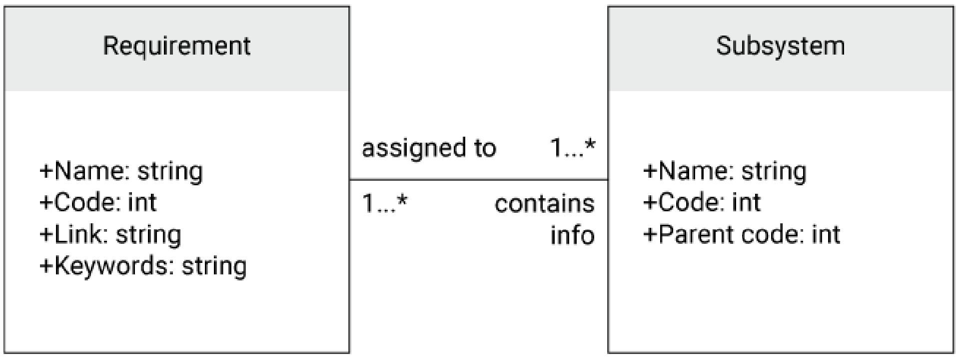

Figure 4. Concept for an information management platform for following and application of requirements in the vehicle development process

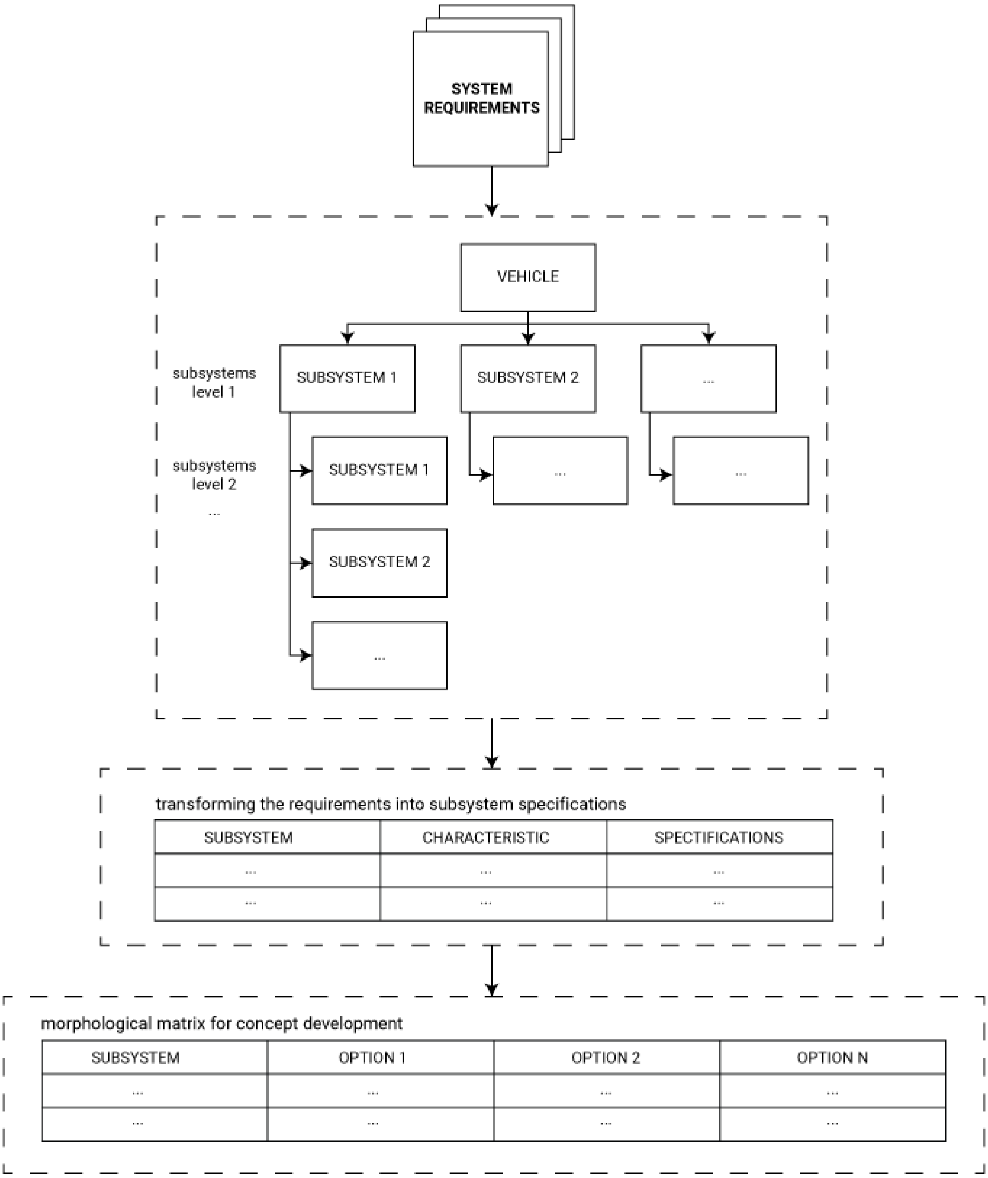

Figure 5. Architecture of the proposed platform – practical use

4. SUMMARY AND FUTURE WORK

Vehicles are complex systems composed of multiple subsystems at different levels which are planned, conceptualized and developed during all of the phases of the vehicle development process, from project planning and working on the conceptual project, to preparing the advanced project and forwarding it for prototyping and testing. It is well known how strict requirements in the form of international and national laws, regulations, standards and directives strongly influence how all those vehicle subsystems and components are designed and constructed. The difficulty of following all the input information, selecting it, combining it and applying it to offer vehicle subsystem solutions that meet the given requirements and are not only suitable to obtain approval, but are also highly safe, ergonomic and environmentally friendly, requires the use of assisting tools for data management. Model-Based Systems Engineering solutions are already being used to represent the system (or product) requirements, functionalities, and logical elements (as well as their relations and connections) in an understandable manner. However, this is usually done at a more advanced level when the requirements can be transferred to specific system functions and technical solutions. What lacks is an assisting tool for systematization of the requirements in an understandable and useable manner which can be used by all team members.

This paper suggests a concept for an information management platform that provides a solution for linking the information from various sources with specific vehicle subsystems and components. This platform is intended to be used at the earliest stages for analyzing and selecting all relevant data that is needed for the development of concepts for specific subsystems – data that helps to properly choose materials, position elements in the interior, choose commercial products that need to be ordered, label components, etc. The benefit of this platform is the possibility to systematize all requirements, update them on a regular basis, avoid omitting important data, and saving all used data for specific projects which can be reviewed by all team members.

However, since the platform is only described at a concept level and illustrated by a class diagram, its practical application cannot be captured at this point. What remains a task for future research is to collaborate with programmers to develop a functional prototype and evaluate it through design case study where a simplified version of one of the vehicles subsystems can be developed. This process will reveal the strengths and weaknesses of the proposed platform and provide directions for further development and improvement.

REFERENCES

[1] Giacomin J 2012 Human centred design of 21st century automobiles ATA Ingegneria dell’Autoveicolo 65(9/10) 32-44

[2] Tumminelli P 2004 Car Design (TeNeues)

[3] Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles 2000 Official Journal L269 34

[4] Bhise V D 2012 Ergonomics in the Automotive Design Process (Boca Raton: CRC Press)

[5] Macey S and Wardle G 2008 H-Point The Fundaments of Car Design and Packaging (Culver City CA: Design Studio Press)

[6] Данев Д 2000 Конструкција на Моторните Возила (Скопје: Графо „Б&С“)

[7] Regulation No 21 of the Economic Commission for Europe of the United Nations (UN/ECE) — Uniform provisions concerning the approval of vehicles with regard to their interior fittings 2008 Official Journal L 188 32-70

[8] Regulation No 17 of the Economic Commission for Europe of the United Nations (UN/ECE) — Uniform provisions concerning the approval of vehicles with regard to the seats, their anchorages and any head restraints 2010 Official Journal L 230 81-118

[9] Regulation No 107 of the Economic Commission for Europe of the United Nations (UNECE) — Uniform provisions concerning the approval of category M2 or M3 vehicles with regard to their general construction 2015 Official Journal L153 1-115

[10] Reed M P, Roe R W, Manary M A, Flannagan C A and Schneider L W 1999 New concepts in vehicle interior design using ASPECT SAE Technical Paper 1999-01-0967

[11] Blanchard B S and Blyler J E 2016 Systems Engineering Management 5th Edition (New Jersey: John Wiley & Sons)

[12] Ye Y, Jankovic M, Kremer G E and Bocquet J-C 2014 Managing uncertainty in potential supplier identifcation AIEDAM 28 339-51

[13] Nunney M J 2007 Light and Heavy Vehicle Technology 4th Edition (Oxford: Butterworth-Heinemann Elsevier)

[14] Reif K 2014 Fundamentals of automotive and engine technology (Wiesbaden: Springer Vieweg)

[15] Bursac N, Albers A and Schmitt T 2016 Model based systems engineering in modular design–a potential analysis using portal type scraper reclaimers as an example Proc. CIRP 50 802-7

[16] Long D and Scott Z 2011 A primer for Model-Based Systems Engineering 2nd Edition (Virginia: Vitech Corporation)

[17] Eigner M Gilz T and Zafirov R 2012 Interdisciplinary Product Development-Model Based Systems Engineering (PML Portal)

[18] Mantsch H J 2019 A holistic approach to vehicle system design Siemens PLM Software 77040-A4 3/19 Y