Cyber Organic System-Model – New Approach for Automotive System Design

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***Abstract*—Modern vehicles are characterized by multiple systems to represent customer functions. The steady increase of these functions leads to an increasing system complexity. This paper describes a structured approach to better master the complexity for future electric and electronic systems. The new approach is based on a combination of two existing system models. The first system model is based on a cybernetic perspective for a management approach for an electrical energy system. The second system model is based on the work in the section ”Organic Computing” of the ”Gesellschaft der Informatik e.V.”. In addition, principles were taken from the human body to design this system approach. Based on these, the Cyber Organic System model is proposed for use in automotive E/E systems. Also, this model focuses the distribution of the overall function to the 3C (Car, Consumer Device, Cloud) locations. Furthermore, the use of this model in automotive software system design will be outlined on the basis of examples.**

***Index Terms*—Cyper Physical System; Electric and electronic vehicle architecture; Bio-inspired computing;**

I. INTRODUCTION

Currently, various approaches for the modeling of complex systems are discussed. In the context of a vehicle data networking in the sense of an overall network, the cybernetic model of fEPM (flexible Energy and Power Management) [1] and the Organic Computing (OC) [2] model appear most promising for automotive applications. Besides of the two mentioned models, there are further models. One of these models is the model of Deutsch, cited in Rittmann [3]. This model is characterized by the combination of regulatory and memory functions. On one hand, the fEPM model has already been tested in a vehicle with a high degree of maturity. On the other hand, the OC model has additional features. This paper discusses the combination of the two models for an overall approach for a bio-inspired software architecture for vehicles. Because the two models have a certain similarity, we discuss the combination of the two models into an overall approach in this paper.

This approach should enable the homogeneous cross linking between vehicles and the (surrounding) infrastructure. IoT (Internet of Things) leads to a continuous increase in the importance and relevance of cross linking. An important feature of the cross linking structure is the distributed function execution and the rising intelligence of these systems.

The rest of the paper is structured as follows. Section II presents the related work. Section III describes the mapping of the fEPM, OC model, and the COS model. Section IV gives an overview of different scenarios of the COS model in a vehicle. In Section V, discusses the applicability of COS in a vehicle. Section VI summarizes the paper.

II. RELATED WORK

In this section, the two models are described, which were combined to the COS model in the following section. In addition, Table I shows other related models. The following models are related: VSM (Viable System Model) from Stafford Beer [4], NASREM (NASA/NBS Standard Reference Model for Telerobot Control System Architecture) from NASA [5], fEPM from Joachim Fröschl [1] and OC from the Organic Computing Initiative [2]. All of these models use the MAPE (Monitor, Analyze, Plan and Execute) or the SMPA (Sense, Model, Plan and Act) pattern [6], [7].

The related models don’t consider about the current development, like IoT and Cloud. Therefore, the COS model is a consequent enhancement under consideration of requirements of the current developments.

A. fEPM - flexible Energy and Power Management

The fEPM [8] is based on a recursive application of the following drafted cybernetic basic model, as shown in Figure 1. This basic model is based on the VSM (Viable System Model) from Stafford Beer [4]. It features 5 system levels. The system level 1 is mostly defined by system values. Beside

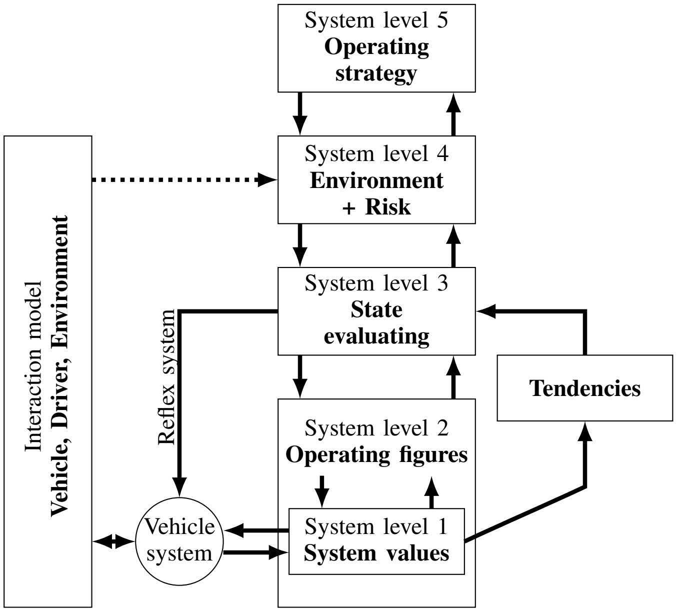

Fig. 1. The fEPM model.

TABLE I. OVERVIEW OF THE RELATED MODELS

	VSM	NASREM	fEPM	OC
Layer #	5	6	5	5
Time of origin	1972	1985	2006	2010
Main characteristic	First biological model	2D Layer model	Technical transformation of the VSM	Learning ability

the physical connections, control and steering functions are included.

The system level 2 condense the system values into operating figures.

The system level 3 determines the operating figures and tendencies that are the analysis of the variation in time of the system values and the operating figures, with deposited knowledge into system states. This level contains also the autonomous, state based system modifications for the purpose of system stabilization.

The system level 4 combines the internal system states with the external system states based on the environment information under observation of the risk; although the modification of a higher hierarchy level is included in the same way.

The coupling of the environment information is filtering the relevant information out of the system specific environment.

The system level 5 contains the operating strategy, which defines the conscious behavior. In this level, the regulation values, also known as modificators, are composed [9], [10].

B. OC - Organic Computing

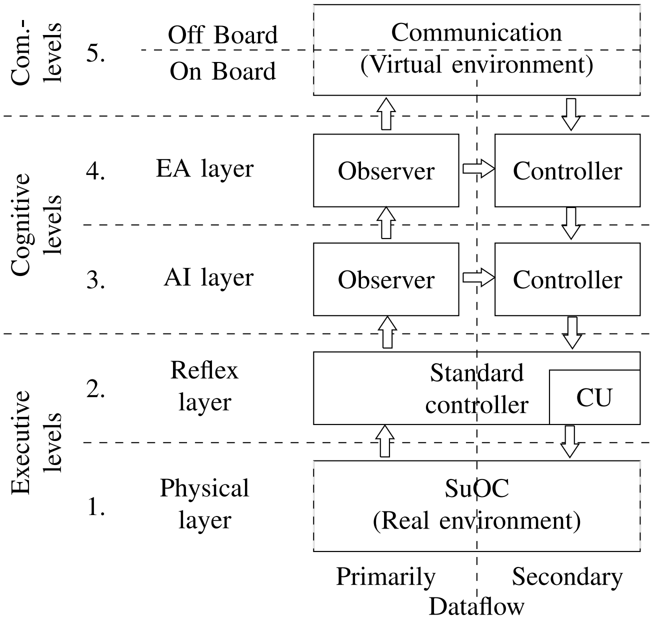

Fig. 2. Reference Model of the OC model (Source: [2]).

Figure 2 illustrates the OC model, which consists out of five layers. The lowest layer is the physical layer, which contains the environment, the actuators, and sensors. The second layer is the reflex layer, a kind of protection layer to ensure fast and correct reaction. The third layer is an AI (Artificial intelligence) layer, which is responsible for quick responses to unfamiliar situations. The fourth layer is the EA (Evolutionary Algorithm) layer to generate long term strategies by using evolutionary approaches - selection, mutation and recombination, - and simulation. The fifth and topmost layer is used to communicate with other components. This communication happens mainly through different (data) models (environmental, vehicle, and driver model), which enables modeling the real world abstract. This layer contains an image of the lowest layer of [2].

III. MAPPING AND DESCRIPTION OF THE COS MODEL

In this section, the identified modules from the fEPM and OC models are explained. This identification of the modules is the necessary basis for mapping these two models. A fundamental fact is to divide the modules to related modules with similar behavior and properties. This implies that any property or object is not included in both approaches. Functional properties of the two models are targeted to combine so that a new model is created with a bigger functional scope. Figure 3 illustrates the mapping of each module. For traceability reasons, each module has its own identifier. We introduce these identifiers in the description of the modules (see subsection III-A), which will be used in the description section of the COS (see subsection III-B).

A. Modules

Consecutively, the particular modules are compared in detail, to define the COS model afterwards.

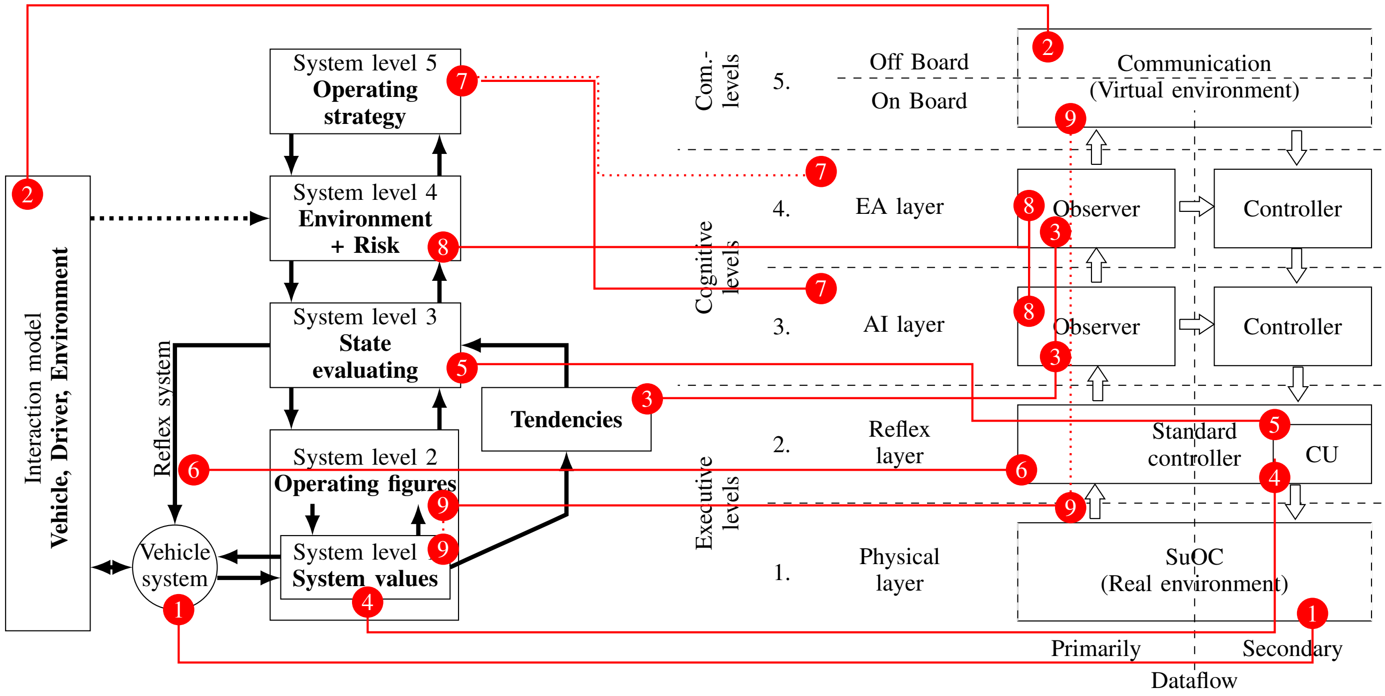

Fig. 3. Mapping between the OC and the fEPM model

1) Sensors (1a): This module includes in both approaches the necessary sensors or other general information sources that are necessary for the investigation of relevant data or system values.

2) Actuators (1b): This module includes in both approaches the necessary actuators and general actuator elements that are necessary for the relevant system modifications.

3) Environment (2): With the environment, all influences from outside the system border are referred. This means on one hand the acquisition and on the other hand the impact of the environment. In both approaches, a real and virtual environment can be distinguished.

a) Real environment (2r): Within the real environment the physical objects are included.

b) Virtual environment (2v): Within the virtual environment instances respective models of the relevant physical objects from the real environment are necessary for the corresponding functions. Because the fEPM makes no distinction between a virtual and a real environment, such differentiation is implemented into the OC module.

4) Data analysis (3a-c): This means that the internal system values should be analyzed. Depending on the system level, the abstraction level changes and a different view on data analysis and data calculation is necessary.

5) Limitation (physical) (4): To avoid data overflow within the modification the so called modificators are limited in the first step of propagation.

6) State evaluating (reflex) (5): Within this level, an assessment of the system values, operating figures, and tendencies is done. If these parameters are out of a defined range, taking care this layer to use values these are within the range of values. The allowed range is defined by tolerability borders wherein the system is able to fulfill explicit operating strategies. If the values are moving out of the defined range, a system reaction has to be initiated like a reflex for stabilizing itself. In a human organism this behaviour is called homeostasis [11].

7) Reflex (execution) (6): To stabilize the system, immediate and direct reactions are necessary. In addition, the operating strategy defines the self-awareness behavior, where some actions must be blocked.

8) Conscious behavior (7): When the system is in a stable state, the system works with a conscious behavior, for example as an operating strategy. While in the fEPM model only one level of conscious behavior is implemented, in the OC-model there are two levels that exist. The lower AI level is conform to the system level 5 of the fEPM model. The upper EA level contains additional evolutionary algorithms to construct a long range operating strategy performance result. Therefore, a higher degree of learning aptitude and self-dependence within the functionality should be enabled.

9) Aggregation of data (8a-c): The accumulated data are collected for an increase of information entropy. The difference in a-c is done in the same matter and argumentation is done similarly in data analysis.

10) Recursivity: Both approaches can be used in a recursive way to reduce complexity. With the use of recursion, the higher instances are unloaded and the lower instances are reinforced to their self-dependence. The lower instances have their own duties and freedom of action. This autonomy is based on the principle of subsidiarity and enables a federal distribution of functionality. This enables a higher capacity of action shown in the example of the OC model in Figure 5.

B. Cyber Organic System Model

The discussed modules can be combined to the cyber organic system model, called COS model represented in Figure 4. Therefore, the single key features of the identified levels are drafted and dedicated to the modules consecutively.

Therefore, it is possible that the left and the right side of the model can be implemented on different Electronic Control Units (ECUs). It is also possible to omit some levels of the model.

1) Communication level: Here, the instructions to the system behavior are partially calculated from modules of a higher hierarchy level and partially from calculated modules of the same hierarchy level received. Furthermore, calculated data with partially higher data entropy is delivered. The different communication partners could stay within the vehicle (on board) or outside the vehicle (off board).
Also, the modules 2v, 3c, 8c are included.

2) Intelligence level: This level includes the specific data processing within the observer unit and a simulation unit within the control unit to learn a long term operating strategy. An additional validation unit is necessary to validate the data and information, which are developed on non-functional verified components.
Also, the modules 2v, 8b are included.

3) Strategy level: Within this level, the learned operating strategy from the intelligence level is used to execute a conscious behavior in a fast and optimal way. Therefore, the necessary information is processed in the observer unit demanded by the control unit.
Also, the modules 2v, 8a are included.

4) Reflex level: In this level, a first and fast analysis in the observe unit (OU) is executed. If necessary, a reflex reaction is immediately initiated. Similar to the human nerve system the conscious behavior is blocked or overruled within the control unit (CU). The human nervous system is spoken of a inhibitory interneuron [12]. Thus, effects self-awarness, - self-protection, and self-stabilization - of the system. In opposite to both higher levels, – intelligence and strategic level – fixed reflexes are used based on an identical data acquisition. Therefore, the freedom of action and possibilities of calculation are limited. Also, modules 5 and 6 are included.

5) Objects layer: Within this level, the data sources and drains of the function model are implemented. On one hand a real hardware for sensors and actuators can be used. On the other hand further software subsystems (e.g. COS stacks) can be embedded.
Also, modules 1a, 1b, 2r and 4 are included.

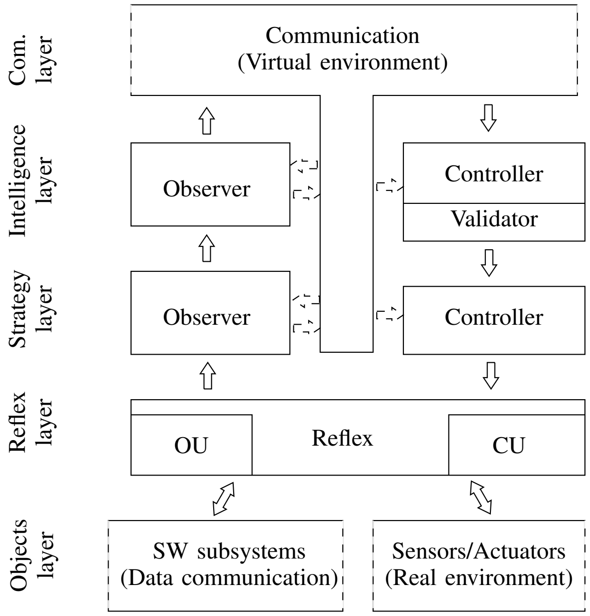

Fig. 4. Structure of the Cyber Organic System model.

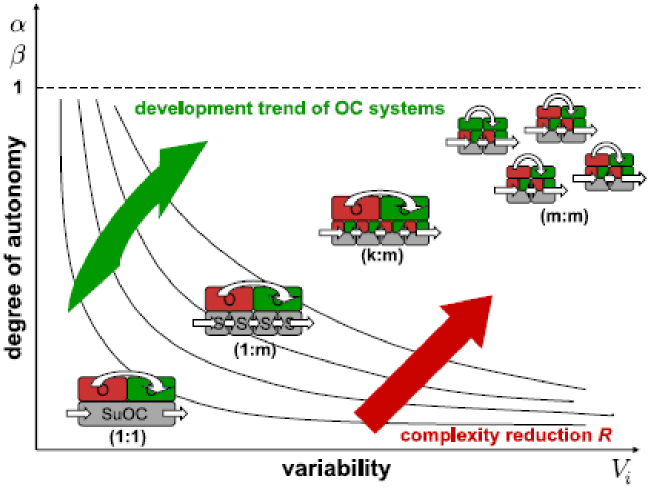

Fig. 5. Degree of variability and autonomy of a OC model in dependence on the system topology (Source: [2]).

IV. THE CYBER ORGANIC SYSTEM MODEL IN VEHICLE

On one hand, the consideration of a function with a COS model is possible. On the other hand using the recursion principle a complete system with many different functions is also possible. First, the complexity of the entire system is reduced. Second, the degree of autonomy and the variability is increased (see Figure 5) [2].

The layered architecture of the COS model enables a flexible and temporary relocation of (partial) functionalities or groups towards further locations (3C).

In the actual hierarchy formation several approaches are possible: a centralized and decentralized approach. This is application may be dependent on not only the platform or model, but even on the equipment of actual vehicle.

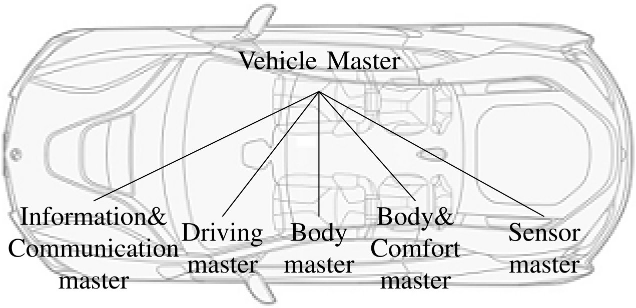

Fig. 6. Central approach in the full vehicle with the COS model.

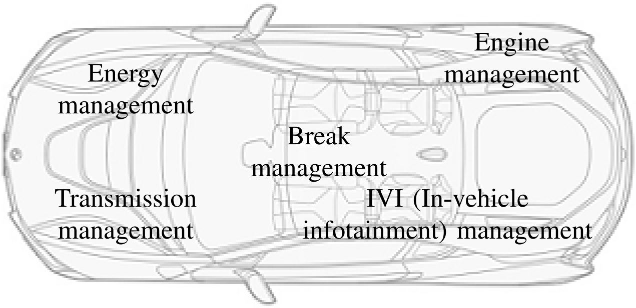

Fig. 7. Decentral approach in the full vehicle with the COS model.

In the centralized approach, there is a vehicle master at the top of the hierarchy and each function is arranged directly or indirectly under this master. In the decentralized approach, independent groups of functions are set up, which also have recursive structures. The extreme case is only having one function in the group. A division of the functions is possible in either domain, see Doman Controller approach according [13], or functional point of view. The size of the groups probably depends on the functions and domain. Different behaviors already exist between domains, as an example, the scaling functions mentioned. With scaling, the functional scope changes. This is reasonable, because of the larger range of functions in the vehicle. A second reason is that existing functionality is being extended. Therefore, their functionality is growing. Which, in turn, results in changes of the partitioning. For example, the light control can be considered. A standard front light requires a smaller software scope, as a xenon or laser light. Another example of the equipment variant can be made the variety of a seat. From pure mechanisms over an electrically adjustable up, to a fully air-conditioned seat with a massage function. While the functions are partitioned at a high scale, a plurality of control devices in a domain matching in another domain are the same case, a high integration strategy is followed. In the case of high integration, several (independent) functions will be combined on one electronic control unit [14].

Figures 6, 7 and 8 outline the different organization options within a vehicle. The topmost element of each organization structure is the coordinator of the underlying elements and the communication partner to another vehicle or cloud. The organization structure depends on the configuration of every vehicle. Probably, neither of the two extreme approaches will be usedInstead, a hybrid approach between both, which frequently occurs in distributed systems, will be used.

V. DISCUSSION

When the two approaches are compared, it indicates that the fEPM approach has a high similarity with the OC approach, as listed in Table II.

The fEPM model follows a single-generation and an individual approach. The OC model follows a multi-generational approach. This difference is given by the fact that the OC approach has besides the strategy an intelligence layer to generate completely new strategy plans through evolutionary algorithm. Also, the fEPM works only with two (online) timeframes. In contrast, the OC approach has three timeframes. In addition to the two online timeframes, an offline timeframe exists, which generates completely new strategy plans. This results in a self-development of the strategy. This leads to a continuous system improvement through targeted objective adjustments and optimization.

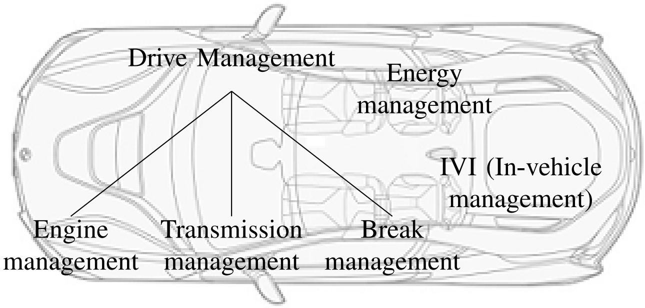

Fig. 8. Hybrid approach in the full vehicle with the COS model.

TABLE II. TAKS AND FUNCTIONS FOR DATA DISTRIBUTION AND PROCESSING

fEPM	OC
1 generation and 1 individual	Multi-generational approach and mutli individuals
Operating strategy is in the system level 5	Operating strategy is in the AI layer
Validation is doing in the switch and limit unit	
Strategy adaptation	Strategy generation
2 Timeframes ●Online (short term/Reflex) (S3) ●Online (medium term/Awareness) (S5)	3 Timeframes ●Online (short term/Reflex) (Reflex layer) ●Online (medium term/Awareness) (AI layer) ●Offline (long term/Self generation of new strategies) (EA layer)

Furthermore, the modular structure of the COS model allows transparent segmentation for the actual function. This enables a flexible partitioning to various control devices or other locations - the 3C locations. This flexibility can not only be used in the development, but also during the operation of a temporary relocation of individual layers is possible. Table III shows a possible distribution of the different layers at the 3C locations. The decisive factors are from today's perspective: communication times, deadlines, energy consumption, safety requirements (Verification and certification of the components), and the necessary computing power. In order to fulfill the requirements of the ISO 26262 (Road vehicles - Functional safety), approaches or related norms from other industries, for example, from the railway and chemical industry, can be applied. The following norms should be mentioned: EN 50159 (Railway applications - Communication, signaling and processing systems), IEC 61508 (Functional Safety of Electrical/Electronic/Programmable Electronic Safety-related Systems) or IEC 62443 (Industrial communication networks - Network and system security). Through these approaches, SIL 3 (Safety Integrity Level) requirements can be fulfilled or made higher. This corresponds to the highest ASIL (Automotive Safety Integrity Level) [15]. This is taken into account the Validator in the intelligence layer.

Because of the software scopes (Lines of code) and the required computing power, the necessary functional validation for the simulation, the intelligence layer is not realizable for all of its functions. In order to ensure operational safety, the COS model contains a Validator. The Validator is used to verify the results from the simulation of a non-functional or unsafe area to use in a functional protected area according ISO 26262.

TABLE III. POSSIBLE PARTITIONING OF THE INDIVIDUAL LAYERS ON THE 3C LOCATIONS

Layer	Car	Consumer Device	Cloud
Reflex	X	(X)	
Strategy	X	X	X
Intelligence	(X)	X	X

Legend:
X = Without any restrictions (X) = Possible with restrictions

VI. SUMMARY

The resemblance of the two models - fEPM and OC - allows a merge into the COS model, which combines the properties of the two models. Due to the same objects and features of the models from the two approaches, the unification could be done with little effort. In addition to the outline of the two models, there was a modularized representation of COS models and a final exemplary application for partitioning functionality in a vehicle.

Furthermore, it was already the (detailed) implementation and use considered, there were many analogies to the functioning of the human body. Also, the CU unit came in consideration the principles of the human body in the COS model. As added value of the combination and the analogies we expected, a revolution of further development of the vehicles system to something like humans, is considered the highest stage of evolution.

The future work should be an implementation and an evaluation of the COS model within a vehicle architecture. The first step is the implementation of selected functions. The second step is the implementation of a representative set of vehicle functions. As a basis for the implementation the results of the development of the fEPM model can be used.

REFERENCES

[1] J. Fröschl and H.-G. Herzog, “A new kind of an Energy Management System,” Bad Boll, April 2015.

[2] C. Mueller-Schloer, H. Schmeck, and T. Ungerer, Organic Computing - A Paradigm Shift for Complex Systems. Springer, Apr. 2011, ISBN: 978-3-0348-0130-0.

[3] G. Rittmann, Der Umgang mit Komplexitt: Soziologische, politische, konomische und ingenieurwissenschaftliche Vorgehensweisen in vergleichender systemtheoretischer Analyse. Nomos, ISBN: 9-783-8487-0990-8.

[4] S. Beer, Brain of the Firm. Chichester, England; New York: John Wiley & Sons, Jun. 1995, ISBN: 978-0-4719-4839-1.

[5] J. S. Albus, H. G. McCain, and R. Lumia, “NASA/NBS standard reference model for telerobot control system architecture (NASREM),” NBS/NIST Technical Notes, no. 1235, 1987, pp. 1 – 98, Last Accessed: 2015-02-15. [Online]. Available: http://archive.org/details/nasanbsstandardr1235albu

[6] IBM, “An Architectural Blueprint for Autonomic Computing,” IBM, Tech. Rep., Jun. 2005, Last Accessed: 2015-02-15. [Online]. Available: http://www-01.ibm.com/software/tivoli/autonomic/pdfs/AC_Blueprint_White_Paper_4th.pdf

[7] J. Hertzberg, H. Jaeger, U. Zimmer, and P. Morignot, “A framework for plan execution in behavior-based robots,” in Intelligent Control (ISIC), 1998. Held jointly with IEEE International Symposium on Computational Intelligence in Robotics and Automation (CIRA), Intelligent Systems and Semiotics (ISAS), Proceedings. IEEE, Sep. 1998, pp. 8–13, ISBN: 0-7803-4423-5.

[8] T. P. Kohler, J. Fröschl, and H.-G. Herzog, Systemansatz fur ein hierarchisches, umweltgekoppeltes Powermanagement, C. Hoff and O. Sirch, Eds. Renningen: expert Verlag, ISBN: 9-783-8169-3010-5.

[9] T. Kohler, J. Fröschl, and H.-G. Herzog, “Systemansatz für ein hierarchisches, umweltgekoppeltes Powermanagement,” in Elektrik/Elektronik in Hybrid- und Elektrofahrzeugen, O. Sirch, Ed. Haus der Technik e.V., 2010, ISBN: 9-783-8169-3010-5.

[10] T. P. Kohler, Prädiktives Leistungsmanagement in Fahrzeugbordnetzen. Berlin Heidelberg New York: Springer, 2014, ISBN: 978-3-6580-5012-2.

[11] A. Faller and M. Schuenke, The Human Body: An Introduction to Structure and Function, 1st ed. Georg Thieme Verlag, April 2004, ISBN: 9-781-5889-0122-4.

[12] J. S. Schwegler and R. Lucius, Der Mensch - Anatomie und Physiologie. Georg Thieme Verlag, Jul. 2011, ISBN: 9-783-1316-8935-1.

[13] H. Krimmel, H. Deiss, W. Runge, and H. Schürr, “Electronic networking of driveline and chassis,” ATZ worldwide, vol. 108, no. 5, 2006, pp. 5–8, ISSN: 2192-9075.

[14] D. Adam, S. Tverdyshev, C. Rolfes, T. Sandmann, S. Baehr, O. Sander, U. Baumgarten, and J. Becker, “Two Architecture Approaches for MILS Systems in Mobility Domains (Automobile, Railway and Avionik),” in International Workshop on MILS: Architecture and Assurance for Secure Systems, Amsterdam, Jan. 2015.

[15] R. Bris, C. G. Soares, and S. Martorell, Reliability, Risk, and Safety, Three Volume Set: Theory and Applications. CRC Press, 2009, ISBN: 9-780-2038-5975-9.