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ENRICHING MECHATRONIC V-MODEL BY ASPECTS OF SYSTEMS ENGINEERING

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Summary: *This paper describes aspects and ideas of Systems Engineering, which can be transferred to the V-model to enrich this. The overall view, the frontload of effort, the handling of requirements and the description of the life-cycle are aspects, which lead to an extended V-model and to the necessity of the definition of the role of the Systems Engineer. The enumerated aspects and the enriched V-model show the possibility to be used as a general framework of the approach of model-based Systems Engineering (MBSE). The paper also underlined the importance of the additional role of the Systems Engineer due to the enormous complexity in the development process of mechatronic systems.*

1 INTRODUCTION

Today mechatronic products are the main constituent of technical products in all industries and markets. With the beginning of the 20th century the industrial revolution brought the automation as an important push of technology and lead the industry into challenges of increasing complexity of the products. The necessity of interdisciplinary working between the classic technical disciplines of mechanics, electronics and information technology indicated challenges for organization, management and technical development processes. Approaches as the mechatronic V model, published in the VDI 2206 guideline, try to support the understanding of the development process. The VDI 2206 provides methodological support for the cross-domain development of mechatronic products [10]. The increased complexity and the increasing challenges make clear that the guideline from 2004 no longer sufficiently focuses the current problems and challenges. To meet the requirements of today development methodologies, aspects are mentioned in this publication, which can improve the mechatronic V-model with the interdisciplinary approach of the System Engineering [1, 2, 10].

2 INTRODUCTION OF THE MECHATRONIC V-MODEL

The mechatronic V-model derives its origin from the information technology. In 1979 Barry Boehm suggested the V model as a procedure model for the development of information technology products. Almost simultaneously, the development of the V model in Germany has been driven. In cooperation with the Ministry of Defense and other federal agencies, IABG developed the V model as a standard model for development, maintenance and modification of information technology systems for the department of defense of the Federal Republic of Germany. Until today the V-model is the one of the most important approaches for information technology development for the German ministries. It is modified from the classic V model from the beginning of the 1990s into a V-model in an extended version, called V model-xt, but transfers the general ideals of three basic phases in the development process. The goal of the V-model is to support the user in understanding the complexity of the development process and its phases. The classic V model of engineering this paper refers to is described in the VDI 2206 “Design Methodology for Mechatronic Systems”. The VDI 2206 aims to bring together the separate development in the different domains. This results in new and unexpected potential and product innovation, but also challenges, such as the definition of interfaces, the communication between the domains and the integration of the individual components in the overall system [10].

In principle the mechatronic V model, which is illustrated in Figure 1, is divided into three phases. After the input of the requirements in the development model, the left wing of the V model describes the phase of the system design. This ends in domain-specific design at the bottom of the V-model, which also includes the engineering and implementation. The third section, the right wing of the model, is the system integration. In Figure 1 is shown by arrows leading back to the left wing, that the verification and validation of the design are a crucial part of the V-model. The goal of the development process is the product, which meets the requirements from input [10].

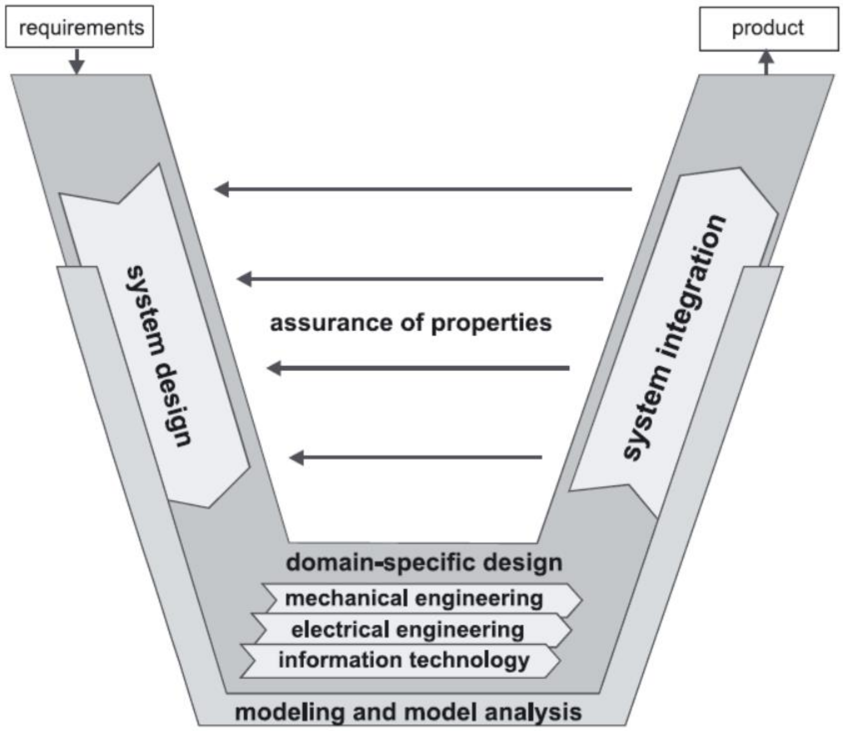

Figure 1: Mechatronic V-model from VDI 2206 [cf. [10]]

The continuous development of the V model brought out several extensions and customized models in recent years. For example, the German Federal Office for Information Technology (BIT) and the American US Department of Transportation (DoT) use extended V models, which were adjusted by changes to individual needs [1, 3, 9, 11].

3 INTRODUCTION IN SYSTEMS ENGINEERING

"Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem: operations, cost and schedule, performance, training and support, test, manufacturing, and disposal. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs" [4, 5]. This definition from INCOSE, the International Council of Systems Engineering, represents the ideas and principals of the approach. Particularly to emphasize are the interdisciplinarity, the frontloading, which describes the focus on the beginning of the development process, and the consideration of the technical as well as organizational and managerial tasks.

In systems engineering, great emphasis is placed on the analysis of the entire life-cycle of a system. This leaves the procedure open to the design of the life-cycle and the use of the various processes. It is defined as the task of the System Engineers, to adapt to the needs for the individual project from the generic processes of the reference models, for example, INCOSE, US Department of Transportation, NASA or the U.S. Department of Defense. This Tailoring process shows on the one hand the liberty the developer has by using the methodology, and on the other hand the low concreteness of the Systems Engineering approach [2, 4, 5, 6].

4 ENRICHING MECHATRONIC V-MODEL BY ASPECTS OF SYSTEMS ENGINEERING

The focus of this paper is the development methodology of the V-model. It will be shown that System Engineering can give suggestions to improve the classic V-model of the VDI 2206. First, some distinctive features and similarities will be explained by the improvement aspect to make it understandable.

The two approaches for the development of mechatronic systems follow essentially the same goal: Both want the developer support cost, time and quality accessible to develop products, processes and services.

Both Systems Engineering and the mechatronic V-model of VDI 2206 are a framework for product development: In both approaches, the core issues of the development process are addressed: Requirements are the basis of development projects. It follows from the obtained cognitions the overall architecture, the architecture of the elements of the different domains, the implementation and following the integration of the elements to build the overall system. In addition, both approaches describe the need for verification and validation and also the early planning of verification and validation processes, shown in the V-model in Figure 1 by returning arrows from the left to the right wing [4, 10].

Model-based procedure:

In contrast to the V-model Systems Engineering does not give a sequence of the different processes or tasks. The INCOSE Handbook only describes the processes and explains, that each process can take place at any time of the development process and that the number of parallel running processes are arbitrary. This explanation follows the first important difference between the approaches: The INCOSE handbook does not illustrate an overall model. The decisive advantage to lead an explicit model is the flexibility that is left to the user to tailor an individual approach. The disadvantage is particularly the generality, which can lead to a lack of understanding by the user. The transfer to the individual situation in the development drops the user in universally valid approaches significantly heavier and requires more individual work. The formation of a concrete model, such as the V-model, also complicates the understanding of the iterative process of product development. Models are often prepared in which the V is repeated several times. This representation should be refrained, because iteration does not mean that the entire V must be run, but that all processes to be carried out one or more repetitions can be iterative [4, 10].

Frontloading and Requirements:

Another important point is the emphasizing of the main focus. Systems Engineering focus on the beginning of the development process. The processes that deal with stakeholder and requirements analysis have major effects for the following steps of the development process. This fact is not adequately represented in the V-model. The classic V-model more or less assumes that the requirements are known and do not require particularly large machining.

Requirements are seen as input. In INCOSE Systems Engineering handbook the requirements analysis process is emphasized with the important steps of elicitation, Systems requirements definition and the definition of the System elements requirements, in the process of architectural design. Needless to say, the implementation of frontloading is a challenge that must be exemplified by management in a project. Putting the largest expense of the project to the beginning, requires great courage and determination on the part of those who are responsible [4, 5].

This frontloading, which refers not only to the requirements, is a critical point the V-model has great potential. A greater emphasis on the early stages, and the integration of requirements analysis in the model are essential for a proper understanding and correct interpretation of the proposed modeling in the development process of mechatronic V-model. With the external presentation of the requirements, illustrated in the classic V-model in Figure 1, this suggests the viewer a little effort and an input with which he can operate with. The reality shows that the relevant requirements can never be fully known and that the requirements change over the period of the development process. Requirements elicitation follows the important processes of translation and formulation, of reviewing and evaluation and of management for the whole project [7].

Figure 2 shows the possibility to extend the classic V-model. The stakeholder definition, requirements elicitation and analysis are implemented at the beginning of the left wing in the classic V-model. The processes were arranged vertically, as a horizontal arrangement does not correspond to reality. It would not have been considered the meaning of the V-model, the possibility and necessity of verification and validation.

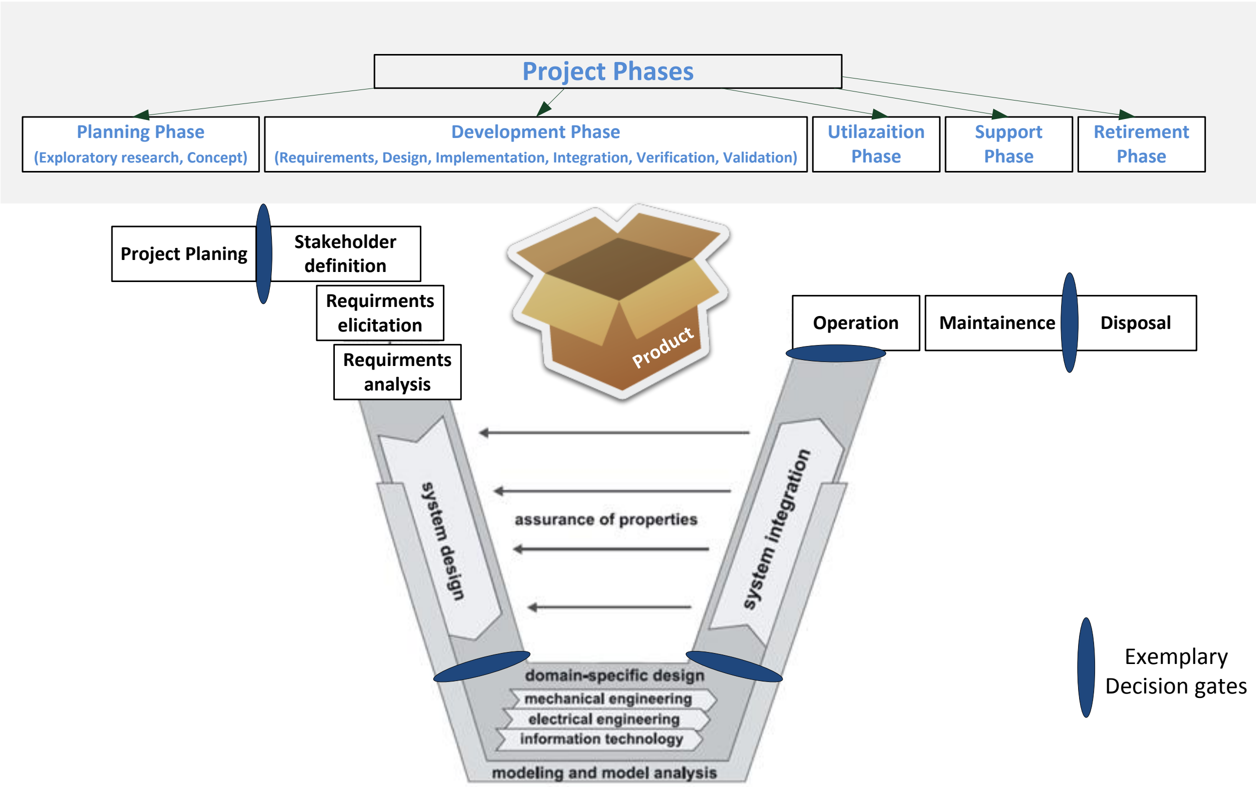

Figure 2: Exemplary extended and enriched mechatronic V-model [based on [10]]

Overall view:

One of the most important basics of Systems Engineering is Systems Thinking. This includes a clear definition of the System, the boarders and as well the interfaces between the System and its environment as the interfaces between the different System elements. Systems Thinking advocates a holistic view for the system. The whole system, its environment and its stakeholders should be considered in focus during the entire life-cycle. This overall view is not integrated in the mechatronic V-model [1, 3].

An exemplary way not to lose sight of the overall system, is the positioning of the system of interest in the center of the V model as shown with the illustration of a package in Figure 2. This is to emphasize that at all stages and in all the individual domains of the development process, the view for the overall system is in focus for the developer. The user should not modify the overall system, but adapt its solution to the requirements and the application of the overall system. This illustration in the center of the V-model have to represent the System. Additionally its life-cycle have to be mentioned in the model, because for understanding the development process it is important to include the stages of the different life-cycles for each product in the early planning of the process. The consideration of the entire life-cycle in all stages of the development process shows the need of additional wings for the V-model not only on the left wing, but also at the right wing. Exemplary stages are the operation, maintenance and disposal stage, which are shown in Figure 2.

Figure 2 above shows a possibility to explain the development process by referring to the whole life-cycle, comparable to other extended V-models, for example the V-model xt, used in the German Federal Office for Information Technology (BIT) or the U.S. Department of Transportation (DoT), which is exemplary shown in Figure 3. The extended V-model of the U.S. Department of Transportation includes the life-cycle in an extra strip above the V-model. The timeline is divided in “phases”, which describe the aspect of time. The V-model is divided into stages. “Stages” describe the substantive delineation of the development process. This classification has been adopted for the exemplary extended and enriched V-model in Figure 2 [9, 11].

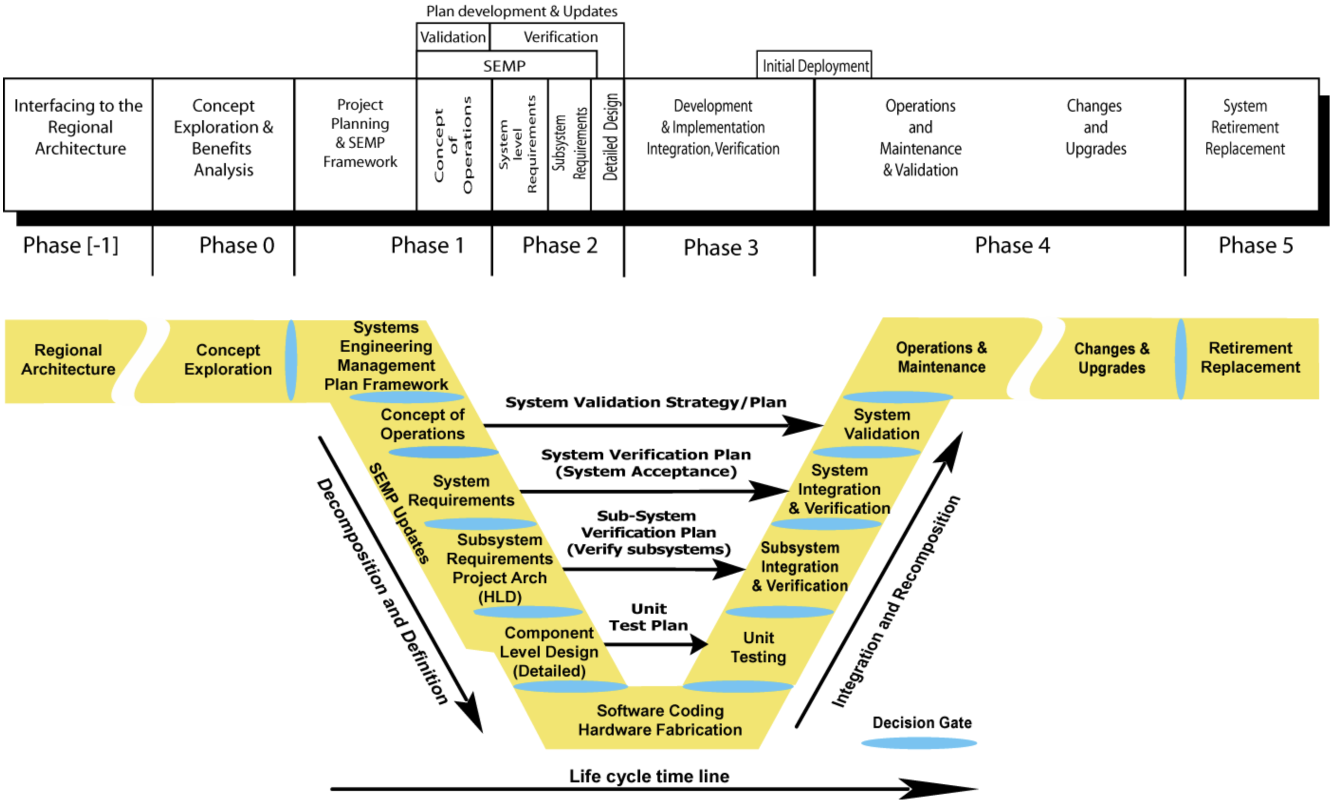

Figure 1: U.S. Department of Transportations extended V-model [9]

Decision gates:

The extended V-model from U.S. Department of Transportation in Figure 3 shows a lot of Decision gates. This gates should be accomplished at the beginning and at the end of every stage, to enable the project, to control the project by management and decide whether the project status is sufficient for the next stage of development process. Decision gates should be integrated in the classic V-model. The VDI 2206 describes the necessity of such gates, but do not describes that in the V-model by an exemplary marking. There are at least two decision gates in any project: authority to proceed and final acceptance of the project deliverable [4, 9]. Exemplary decision gates are shown in the exemplary extended and enriched V-model in Figure 2.

5 THE ROLE OF THE SYSTEMS ENGINEER

The aspects mentioned and exemplified for improvements of the V-model, show the change in the situation in the development process of complex mechatronic systems. Neither the classic developer which is a technical expert in his discipline, nor the project manager, which essentially has the economic and organizational aspects in focus, are capable of handling complex projects in sole responsibility. For example, a developer of a mechanic unit of a complex system hardly meet the demand to be always familiar with the overall system and its life-cycle. Not this mechanic developer is responsible to realize this overall view, but the project leader. This project leader is responsible that the specifications are both given right to the individual developer, as well as developed the element corresponds to these specifications. That no common role can handle the task the extended and enriched V-model leads to, shows the need to introduce a new and redesigned role: The Systems Engineer will be a combination of a developer and project manager. He has good technical understanding as a basis, usually he is even expert in one discipline, and also brings the qualities of a project manager, such as the processing of organizational and management tasks [4, 6, 8].

The Systems Engineer is not intended to replace the project manager or developer, but deal with the tasks of increasing complexity as an additional role. Project Manager and Systems Engineer are responsible for the project together. The Systems Engineer is basically responsible for the technical processes, the project manager for organizational processes. The cooperation between the two roles is essential. The shared responsibility for the project requires the two roles to an intensive cooperation. Figure 4, which comes from the Systems Engineering Handbook NASA, provides the tasks of the Systems Engineer, the project manager, here described as project control, and the common challenges to be faced. The amount of the tasks described shows that the complexity can hardly be handled by a single role.

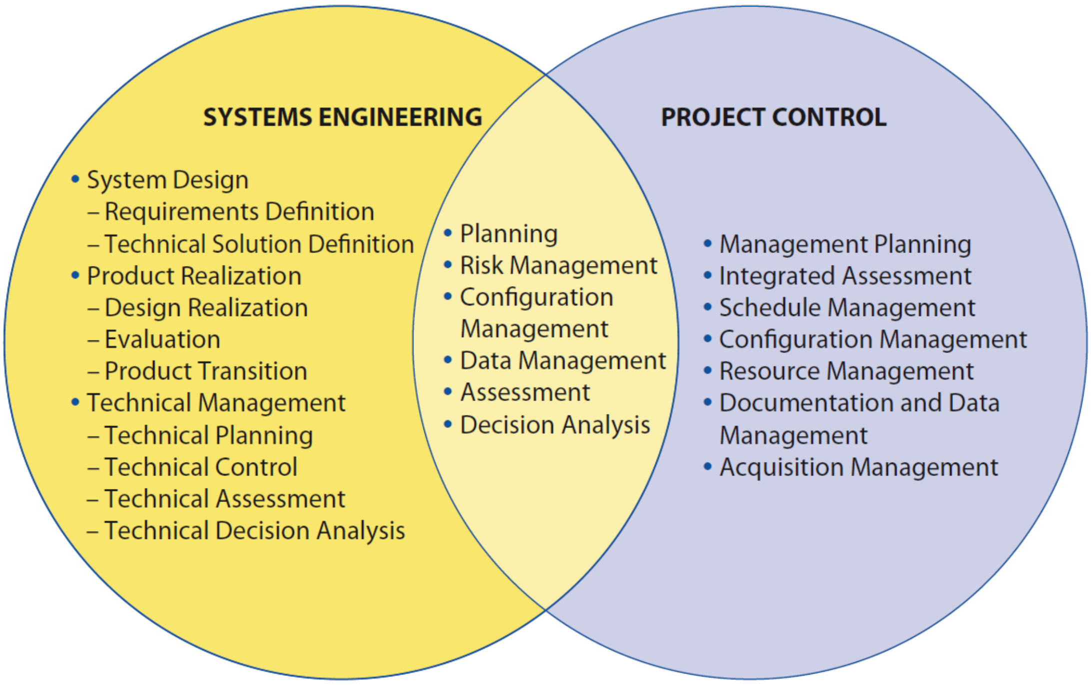

Figure 4:Tasks of Systems Engineering (Systems Engineer) and Project Control (Project Manager) [6]

Important for the understanding of roles in complex technical project is the fact that neither the Systems Engineer nor the Project Manager trigger and control the project. This means for example the passing of the decision gates. The systems engineer and project manager present the status of the project in the decision gate meeting and the management entity, that has been commissioned the project, evaluate the system integrity. Systems integrity means the balance of the business aspects, the budget and the technical aspects.

This role, which is already established in Systems Engineering accordance with the

Handbook of INCOSE, should be also applied in the V-model. The VDI 2206 describes the structure and composition of a possible project teams, but does not define the role of leaders, who are responsible for the project. The complexity makes the distribution of the development methodology in technical and project management tasks necessary [4, 6, 8, 9].

6 CONCLUSION AND FUTURE PERSPECTIVE

The purpose of this paper is to show that the development methodology of VDI 2206 is been described very well by using the V-model, but must be expand and restructured to be able to handle complex challenges. The ideas of Systems Engineering can be very helpful. The resulting extended V-model can be used not only to expand VDI 2206 but also to describe a model-based approach of the methodology of Systems Engineering. The extended V-model is able to be a framework-model for Model-based Systems Engineering, where additional models of other processes and disciplines are subordinated. As described in these embodiments, in addition to modeling is particularly the role definition in the development of complex systems of extraordinary importance.

Future tasks include the analysis of other models for illustration of the development process for mechatronic systems. The modeling of the ideas of Systems Engineering, such as the inclusion of the life-cycle, the view of the overall system and the resulting role of the Systems Engineer, must be assessed and extended based on user experiences of the Systems Engineering methodology. The discovery of an extended model according to the specifications of VDI 2206 and the framework for the use of model-based Systems Engineering go hand in hand, since both methods have the goal to develop complex mechatronic systems. The resulting role of the Systems Engineer must also be clearly defined in the future and his areas of responsibility are defined. For both topics industrial studies are needed, as well as scientific research of the existing roles and their theoretical expression. The tasks of the Systems Engineer must be accompanied by the modeling. Depending on the individual tailoring of the methodology, the tasks of the System Engineer should adjust the reference model used for the description of the procedure for the development process.

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