Systematic Implementation Of Virtual Product On The Example of *DriveSets*

Angel Bachvarov[1]

Abstract – **The Virtual Product concept is explained as an internal rationalization and facilitation of the engineering process in the small-scale companies. A systematic design approach for implementation of modular positioning systems as a Virtual Product is presented. The implementation of the concept is discussed on the example of a case study.**

Keywords – virtual product, systematic design, modular positioning system

I. Introduction

In the last decade a significant number of research projects deal with closing the gap in the production chain beginning from the planning stage up to the putting the technical products in operation within a common infrastructural framework of software tools with compatible interfaces and "virtualization" of the manufacturing [1].

The Virtual Manufacturing is based on following three main principles:

- **Model and Simulate**, which means to do manufacturing activities „virtualy in the computer";
- **Predict and Evaluate**, which means to determine what would happen if the activities were actually carried out;
- **Make Improvements**, before the actual manufacturing is done.

The different VM-models are discussed in details in [1,2]. A simplified schematic comparison between the Virtual and Classical Manufacturing could be obtained from Fig. 1. It is obviously that the Virtual Manufacturing could be used for enhancement and optimization of the real Manufacturing as far as the VM could be observed as an image of the "real-world" manufacturing processes and its output could be applied directly for improvement of the existing production practice. Introduction of the virtual production strategies has as consequence a lot of benefits for the vendor which could help him to ensure his market share. The most important among there are:

- **Adaptation and quick reaction** on changed market conditions;
- **Customization and utilization** of manufacturing resources selected for their abilities;
- **Higher efficiency** allowing low cost, and low volume production;
- **Better management** of the supply chain trough on-time deliveries, lead time compression, inventory and costs reduction.

Implementation of such production strategies for life-cycle management of the technical products is a very complex task and demands significant financial and research resources. It raises some issues related to a new corporate culture, data protection, information infrastructure, complex engineering knowledge communication, standards development, etc. Due all this they are presently an exclusive privilege of the large production companies, clusters of companies, global partnerships and big research institutes. Their introduction in the small and medium-scale companies is still problematic.

Different scenarios for the use of VM in the small and medium-scale companies are reasonable, e.g. Component catalogues, Digital procurements, Electronic bids, Partner selection, Customisation etc. Recently a trend for developing of so-called Virtual Products is established.

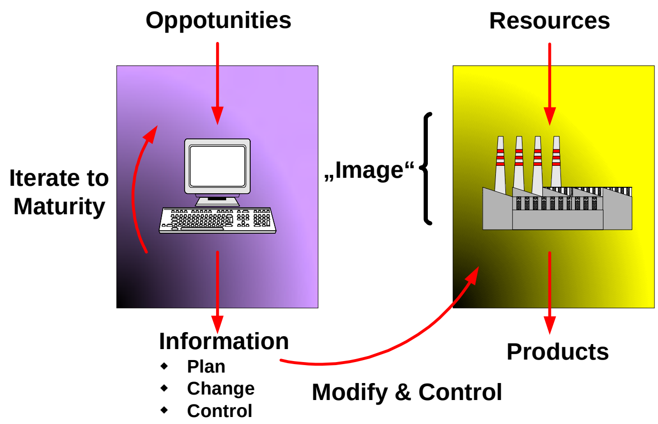

Fig. 1 Model of VM and "classical" Manufacturing

Here the concept of *"the virtual product*" concerns not only the conventional computer aided planning and simulation of the developed products. According to the adopted definition "the virtual product" is a technical system, which allows instant and direct access and management from every PC, everywhere and on every stage and level of its production

[1]Angel G. Bachvarov is with the Faculty of German Engineering and Management Education, TU – Sofia, Building 10, Room 10214, 8 Kliment Ohridski, 1756 Sofia, Bulgaria, e-Mail: a_bachvarov@tu-sofia.bg

cycle in order to increase the competitiveness and to guarantee the market share of the vendor through high diversity of the covered technical parameter ranges and possibility for promptly development and “materialisation” of pre-engineered “custom-tailored” solutions according to the individual clients needs. In this sense the Virtual Product could be seen as an important engineering technique for internal rationalization and facilitation of the engineering process in the small-scale companies.

According to the market research carried out by the authors in 2002 covering Germany, Austria and Switzerland a significant number of the small-scale production companies acts mostly only as integrators of OEM modules in fully functional technical systems [3]. The application of the “Virtual Product” concept is especially favourable in such cases. A common approach for development of Virtual technical products is still missing.

II. Systematic Design Approach

The strong competition on the global market creates a need for precise selection of production devices with optimal technical and economical characteristics and their best possible adaptation to the specific requirements of the customers. The electric driven modular positioning and handling systems offer opportunity for this. The available on the market systems are limited in respect of diversity of their operational properties [3]. In consequence of this fact significant additional efforts are required every time in order to customise these systems to the constraints and technological limitation for every single automation problem.

As a design object the modern modular positioning and handling systems have the following features:

- they are complex technical systems;
- they are described with diverse sub-systems, structures and parameters;
- their development imposes observance of a large number of requirements and constraints and is developed with significant financial and temporal resources.

The importance of timely and efficient product development requires quickly and directly determination of the possible solutions. That could be achieved by adopting design procedure, which is flexible, transparent, and capable of being planed, optimized and verified. As Pahl, G., Beitz,W. [4] claim the systematic design approach provides an effective way to rationalize the development and production processes. Such design method is also prerequisite for continuous computer support using stored data. Systematic processing [5] makes possible consideration of cost and quality of the designed products on early stage, which enables better market chances. In order to implement a modular positioning systems as a Virtual Product range a special design procedure was proposed.

The method has three stages and includes following elements:

- Virtual Product framework;
- Functional structure of a modular handling system;
- Classification of the functional units performing the the functional structure;
- Morphological matrix for composing the functional units set of the single sub functions;
- Algorithm for generating (syntheses) the possible system structures;
- Selection of the optimal handling system;
- Validation procedure.

Within ***first stage*** sets of functional entities performing the sub-functions are combined through a morphological matrix technique in complete functional structures (see Table 1 and Fig. 2). The first column of the scheme contains the sub-functions of the functional structure and the instances of the correspondent functional entities (sub-modules) are entered in the rows. The possible solutions could be obtained by combination trough systematic variation of the modules (functional entities) performing the single sub-functions according to the resolved functional structure entered in the morphological matrix.

The main problem with such combinations is ensuring the physical and geometrical compatibility of the functional entities to be combined. The compatibility of functional entities is tested through an additional compatibility matrix. If compatibility (full or partial) between two functional entities exists, the instance of the required connecting element (mechanical, electrical or software) is mapped in the correspondent cell of the scheme. This enables the combination only of the compatible instances of the correspondent sub-solutions.

Table I

Morphological Matrix

Sub-function	**Functional Entity**	**Instances of functional entities**			
		1	**2**	**...**	**m**
1. Control	*Control unit*	E_{11}	E_{12}	..	E_{12m1}
2. Amplification of the control signals	*Motor driver*	E^1_{21}	E^1_{22}	...	E^1_{2m2}
3. Transformation of the electrical energy in torque	*Electric motor*	E^1_{31}	E^1_{32}	...	E^1_{3m3}
4 Amplification of the mechanical energy	*Gear*	E^1_{41}	E^1_{42}	...	E^1_{4m4}
5. Transformation of the torque in force	*Linear actuator*	E^1_{51}	E^1_{52}	...	E^1_{5m5}
6. Fixing the load position	*Sensor*	E^1_{61}	E^1_{62}	...	E^1_{6m6}

where: E^i_{nm} – functional entity; i – indicates axis No.; n – sub-function No.; m – functional entity instance No.

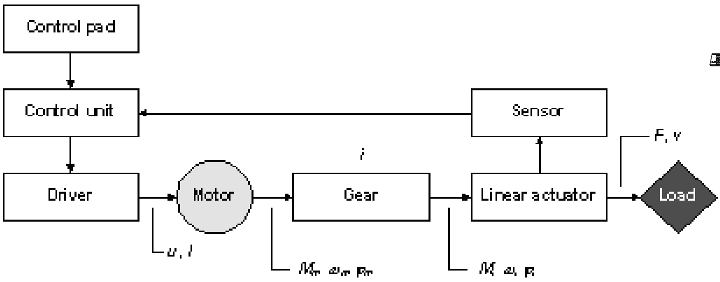

Fig. 1. Simplified symbolic model of a linear positioning system

Within ***second stage*** a selection of the optimal positioning and handling system have to be done. For the systematic approach the solution field is very wide. The task is to find the optimal combination of the available functional entities performing the system sub-functions under preliminary requirements and constraints related to the technical and economical characteristics of the system (price, weight, long-life etc). That is a multi-objective optimization problem (MOP) and with following mathematical representation:

$$\textit{Minimize } F(\vec{x}) = (f_1(\vec{x}),\ldots f_p(\vec{x})) \quad (1)$$

$$\textit{under constraints } g_i(\vec{x}) \le O, i = 1,\ldots,m, \vec{x} \in \Omega$$

The analysis of the problem has found its following special features:

- huge number of possible variant solutions;
- discrete character;
- need of evaluation of the evolved structures based on a set of technical and economical system characteristics of different physical meanings and dimensions;
- optimisation goals of different priority level.

In order to obtain diverse results three essentially different optimization techniques were studied [6,7], e.g.:

- Weighted sum method;
- Minimax Goal Programming;
- Vector Evaluated Genetic Algorithm (VEGA) based optimisation by switching objectives.

Within ***third stage*** a graphic form model describing the physical characteristics of the proposed structure: e.g. spatial, geometric and topological data is built. Tests are run through simulation to determine whether the intended purposes are satisfied by the found structure.

A web-based tool for computer aided selection of modular linear drive systems with up to three axes to support development of the virtual product was developed based on the presented approach excluding third stage, which is not yet implemented as web-based function. It has a classical 3-layer model: data input interface (front end client), computing algorithm (server) and database at back-end. Fig. 3 shows the software architecture and data flow within the system.

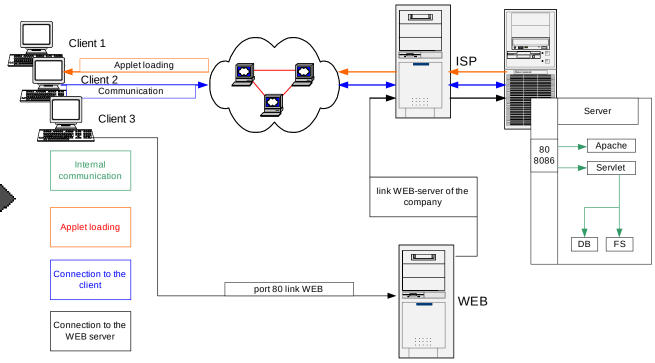

Fig. 3. System architecture and data flows

At the end of the work cycle a graphic 3D form model is generated with *Autodesk Inventor* and is used for crash-tests, FEM-analysis etc. Presently a migration to *SolidWorks* is undertaken.

III. Case Study Drive Sets

The aforesaid method and tool were used as a core element in the development of ***DriveSet***-family as a part of an R&D project studying feasibility of the introduction of a virtual production model in ***Systec E+S GmbH***. ***Drive Sets*** were designed in a scalable framework as parametric range of modular linear positioning and handling systems with application in the industrial and laboratory automation, evolved through the integration of OEM-modules. The framework of the parametric range was built by systematic variation and full combination of 6 technical and structure system parameters (load carrying capacity, maximum speed, repeatability, operating area, design type, stroke) mapping every combination as unique ***DriveSet***-family member.

For the purposes of an unique identification of the single entities of the ***DriveSet***-family a convention for the following the system properties groups was adopted (Table 2):

- ***operating properties*** – all parameters defining the system input and output;
- ***structure properties*** – they describe the spatial structure of the system and geometric relations between the system elements.

The defined system properties, excluding the stroke, are coded with an art of semantic code. Through their systematic variation the set of the possible variants is generated. These possible variants build the framework in which the ***DriveSets***-family evolves. Every unique property combination obtains a single number identifying the correspondent representative of the family (see Fig. 4). The network model of the ***DriveSets***-family could be seen on Fig. 5. In this manner some 144 basic structures were specified.

TABLE 1
SYSTEM PROPERTIES OF THE DRIVE SETS-FAMILY

Operating properties	Structure properties
Load carrying capacity: describes the capacity of the system to carry a definite load. That is the maximal paying load which the system could accelerate up to the maximal speed in 100 ms.	**Operating area:** describes the shape of the operating area where the system TCP could be positioned. The shape of the operating area is related to the type of the kinematical structure and number of the spatial axes.
Speed: indicates the maximal system speed.	**Design type:** indicates the spatial arrangement and fixing of the single mechanical modules: e.g. gentry.
Repeatability: indicates the repeatability class of the system.	**Stroke:** indicates the maximal stroke along a single spatial axis.

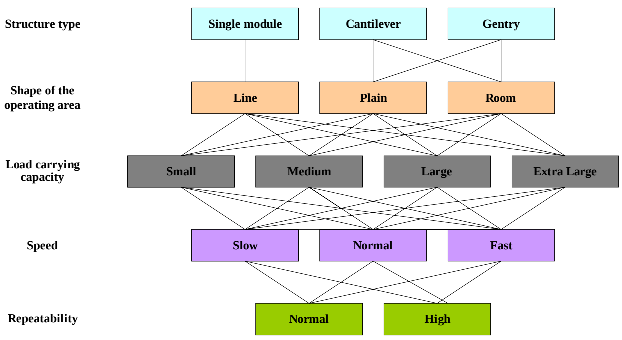

Fig. 4. Network model of *DriveSets*

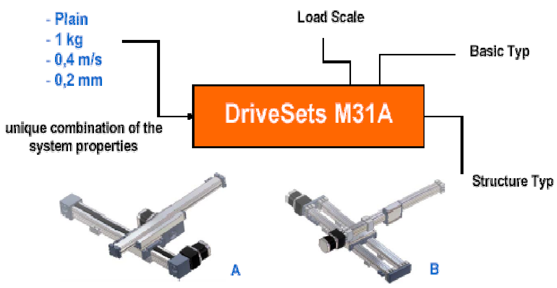

Fig. 5. Identification of *DriveSets*

The values corresponding to the used semantic code are determined on the ground of statistic processing and analysis of the market figures for the past three years delivered by ***Systec E+S GmbH*** as well as an inquiry made among 114 companies from EU, identified as potential customers. The optimal solutions for 98 of the predefined within the frame positioning and handling systems were found and implemented as "virtual products", 3D-models and product specifications needed for the fast production is stored in the database. Now the customer could select among the offered pre-engineered basic structures and find the system most appropriate for his specific needs using a simple selection procedure (with hard copy catalogue or online). Further he can choose the stroke for every single axis of the system. 10 standard stroke lengths are available.

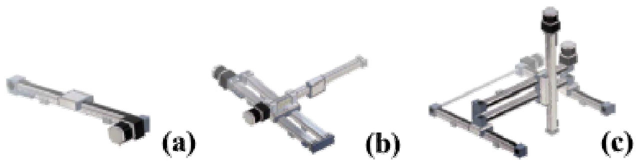

Fig. 2 3D-models of *DriveSets*-family representatives:

(a) M2 (single module; line; 1kg; 0,1m/s; 0,025mm), (b) M31B (cantilever; plain; 1kg; 0,4m/s; 0,2 mm), (c) M90 (gentry; room; 0,4 m/s; 0,2 mm)

More detailed information about *DriveSets* is available from <http://www.drivesets.de>.

IV. CONCLUSION

The Virtual Product are an important engineering technique for internal rationalization and facilitation of the engineering process in the small-scale companies.

An approach for systematic design of modular handling system applicable in the industry for the purposes of an attempt for introduction virtual manufacturing practices in small-scale companies is developed.

The adoption of the systematic design method for development of Virtual Products:

- ensures the determination of an optimal solution due its systematic nature;
- reduces the effort and saves time in respect to the solving of the design problem;
- cuts off the cost within development stage up to 40%;
- possesses improving potential and wide application field;
- was successfully applied in the solving of real-world design.

REFERENCES

[1] P. Banerjee, ,D. Zetu, *Virtual Manufacturing*. John Wiley & Sons Inc. NY, 2002.

[2] D.S.Nau, J.W.Herrmann, W.C.Regli *Virtual Factories*, Institute for System Research, University of Maryland, 2002.

[3] A. Bachvarov, T. Wolter, „Neue Strategie für systematische Entwicklung von Antriebssystemen", Automation & Design Kompendium. München. pp. 214 – 218, 2003.

[4] G. Pahl, , W. Beitz, *Konstruktionslehre*, Springer-Verlag. Berlin Heidelberg, 2000.

[5] *VDI 2221: Systematic Approach to the Design of Technical Systems and Products*, VDI-Verlag GmbH. Dusseldorf, 1998.

[6] I. Boyadjiev, I. Malakov, "Selection of Optimal Structure Variant of Assembly Systems", Машиностроене 2-3, Sofia, pp.18-24, 1999.

[7] K. Deb, *Multi-Objective Optimization using Evolutionary Algorithms*, John Wiley & Sons Inc. NY, 2002.