UDK: 62.002.2:681.3.06
COSATI: 12-01

Presentation of Configuration Knowledge by a Matrix-Based Configurator

Krešimir Osman[1)]
Mato Perić[2)]
Dragi Stamenković[3)]

Configuration matrices are used in the development of products for the documentation of modular product structures. They represent a visual tool for managing configuration knowledge changes, so it can be said that configuration knowledge changes concurrently with the impact of product development on existing products. The presentation of knowledge via such matrices facilitates the management of configuration rules in environment changes. We attempted to provide a presentation that would be easily comprehensible and adapted to human abilities. In addition to matrices, the paper also presents a matrix-based configurator and its design.

Key words: **configuration knowledge, configuration matrix, matrix-based configurator.**

Introduction

THE development of configurable products is one of the main directions in resolving product adjustment to customer requirements [1], i.e. it aims to achieve easier product management and impact on certain parts of the product variant life (orders, sales, manufacture and maintenance). We treat product configurability as an activity to fulfil customer wishes by creating a product from previously defined components. Today, this is present in numerous enterprises in different industries. In order to develop configurability, the product must be prepared. In other words, it must be modularized and composed of previously defined components. Product configurators are computer tools [2], enabling inclusion of customer wishes in the development of desired configurable products and representing a set of rules they create in the process: component and circuit specification, manufacturing structure and complete documentation. The result of the configuration process is a configuration describing the product variant to be manufactured for an order. It also may result in several configurations. This is actually an iterative process by which we are able to obtain a result that may not fully meet the requirements set. In addition to all general problems with any computer program intended for process automation within the enterprise, all existing applicable configurators have two specific problems. The most difficult one is long-term management of engineering knowledge in the configuration model and configurators. The second problem is the diversity of approach to modelling and ensuring functions in systems provided by different suppliers, which represents a difficulty for the enterprise when deciding which specific system best meets its needs. Regarding the first problem, we can say that the presentation of configuration knowledge for configurable products is very important. This knowledge should be accessible visually [9] to provide a base for effectiveness of the configuration process. Configuration knowledge should be documented to be able to use it as a base for the configurator and the structure of generic products obtained by configuration models establishes a base for the variability of the tool, which may help enterprises using configuration products as a base for fulfilment of customer requirements. The problem with configuration products is a simple presentation of information associated with the products as support to enterprises. As long as this knowledge is not presented visually, the modularity and configurability are often incomprehensible in working environments, while the manufacturability is not considered. All this affects the implementation and use of the configurator, as well as the changes occurring during the life of a product. This paper mostly focuses on an effective use and a presentation of configuration knowledge as a support to enterprises. For this purpose, we attempted to provide an easily comprehensible presentation of configuration knowledge, adjusted to human abilities. In addition to configuration matrices that would be used for the presentation of modular configurable product systems, we also present a framework for the presentation of such configuration knowledge.

Presentation and the Process of Creation of Configuration Matrices

According to [3] that presented the idea of concrete, valid and complete product configurations, the configuration model elements require that everything that is known about them and everything necessary for the process is taken into account. The main purpose of configuration

[1)] Faculty of Mechanical Engineering and Naval Architecture, Ivana Lučića 5, 10000 Zagreb, CROATIA
[2)] Bureau of Energetics and Mechanical Engineering Ltd., Petrovaradinska 7, 10000 Zagreb, CROATIA
[3)] Termoelektro Ltd., Uralska 9, 11060 Belgrade, SERBIA

matrices is to satisfy the needs of the configuration model for each product, as mentioned above. The development of configuration model configuration [4] is established as generic. The configuration matrix field [5] is associated with the changes causing the sales process and changes in product marketing, manufacture and development, as presented in Fig.1.

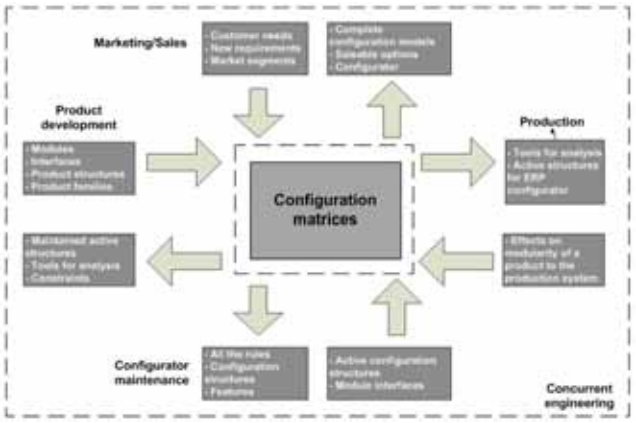


Figure 1. Role of configuration matrices

The most important thing with configurators is the management of the configuration rules and integration with the databases providing a support system by automatically providing the configuration system with rules, generic structures, features and other options as information. The manipulation of the configuration rules is provided via the configurator, by which we reduce manual efforts in data changes. Active modules are presented in the configuration matrices, while the ERP/PDM/CAD systems contain fixed structures in their databases, which means that active parts can always be defined by using the generic structures available in the matrices. The data in the ERP/PDM/CAD systems are connected with the generic structures. Configuration matrices are made by the MS Excel computer program for tabular calculations because of the simplicity of recording and compatibility with the Windows operating system. For this purpose, we can also use computer programs developed for matrix handling. They are used as databases for storage of configuration knowledge. The analyses and selection of a product are carried out by an administrative interface programmed in the Visual Basic.NET 2005 program language as ASP.NET web applications, so they can be used as services via intranet or internet. The database used for the configurator is an MS SQL server 2005 and we use SQL queries for database searching.

Configuration matrices may be created for both new products and existing ones. The paper deals with existing products. We already know [6] that configuration model modeling is very difficult and require a substantial amount of time. In addition, every enterprise has a few people who know how to configure a specific product. The matrix creation process for an existing product is carried out as follows:

1. Obtainment of required configuration knowledge by interviewing experts,
2. Definition of the generic option list,
3. Definition of the generic product structure,
4. Definition of the variable parts of the product structure,
5. Definition of the basic parts of the y structure machines,
6. Definition of the sales option sequence,
7. Generation of the square matrix by options and modules according to the sequence
8. Definition of the module dependence on the options,
9. Matrix finalization.

Table 1. Cooling Generator Product Variants

Type of condenser	Type of fan	Chiller model	Position	Technology	Refrigerant type
Air	Axial	RZA 1 5-35	outdoor	scroll compressor	R 407C
		RZA 2 5-24	outdoor	scroll compressor	R 407C
		RZA 3 30-95	outdoor	scroll compressor	R 407C
		RZA 4 30-95	outdoor	scroll compressor	R 407C
		RZA 5 40-200	outdoor	screw compressor	R 134a
		RZA 6 40 - 200	outdoor	screw compressor	R 407C
	Centrifugal	RZC 5-10	indoor	scroll compressor	R 407C
	Separate condenser	RZK 1 5-24	indoor	scroll compressor	R 407C
		RZK 2 40-200	indoor	screw compressor	R 407C
Water		RA 1 5-72	indoor	scroll compressor	R 407C
		RA 2 40-200	indoor	screw compressor	R 134a
Hydraulic module		RH 10-30	indoor + outdoor		

Table 1 shows all sales options and all cooling generator product variants. Fig.2 presents one of the configuration matrices (cooling generator with an air-cooled condenser). According to the research performed for the author's last paper [7], through the MFD method [8], items 1, 2 and 3 are already defined.

The integration of the matrices with the configurator is of great importance as the frequency of changes is relatively high. In such cases, the configuration knowledge changes concurrently with the impact of product development on the existing products. The configurator saves data in the system for each configuration model and each model version. When integrating the matrices and the configurator, all features and elements required for configurator setup will be automatically downloaded to the configurator from the configuration matrices. We believe this configurator's database is automatically updated and it manages data. Fig.3 shows the tools and features provided to the configurator by the configuration matrix:

a) Configuration matrix management interface:
- generic structures
- manufacturing configuration rules
- marketing configuration rules

b) integration with the configurator

c) visual presentation of configuration knowledge

d) generic manufacturing structures

e) generic feature structures

f) basic machines

g) feature families

The experience of configurable products changes throughout their lives. In configuration knowledge, critical changes are related to options and their dependencies between modules and themselves, modular interfaces and their connections. Every time the generic product structure occurs, the configurator base must change. The potential problem here is that there are already configured products in the database and when the user wants to change something in them, the configuration knowledge will not affect the change process. In addition, interfaces may change over time, which may render some modules unnecessary. As a result, when manufacturing begins, we may have old module revisions or completely wrong modules.

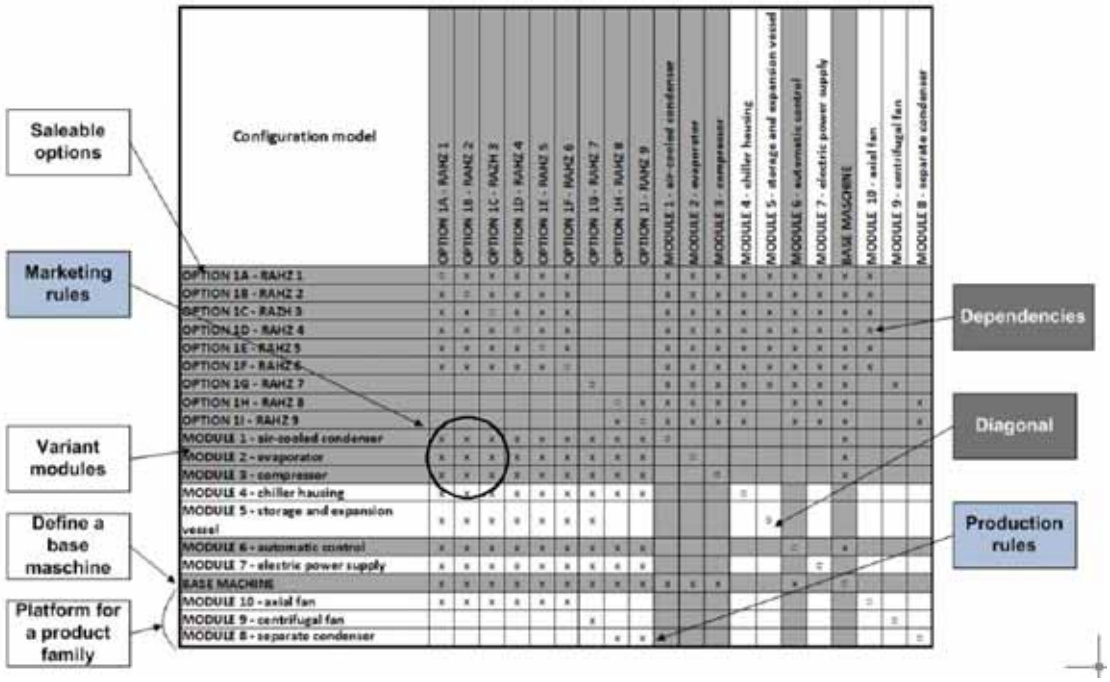


Figure 2. Configuration matrix for a product variant (cooling generator with an air-cooled condenser)

A configuration matrix is based on the matrix representation of a digraph [9] (i.e. directed graph) which is a binary (i.e. a matrix populated with only zeros and ones) square (i.e. a matrix with equal number of rows and columns) matrix with m rows and columns, and n non-zero elements, where m is the number of nodes and n is the number of edges in the digraph. The matrix layout is as follows: the system elements names are placed down the side of the matrix as row headings and across the top as column headings in the same order. If there exists an edge from the node i to the node j, then the value of the element ij (column i, row j) is unity (or marked with an X). Otherwise, the value of the element is zero (or left empty). In the binary matrix representation of a system, the diagonal elements of the matrix do not have any interpretation in describing the system, so they are usually either left empty or blacked out. Briefly, binary matrices for system modelling are useful in systems modelling because they can represent the presence or absence of a relationship between the pairs of elements of a system. A major advantage of the matrix representation over the digraph is in its compactness and ability to provide a systematic mapping among system elements that is clear and easy to read regardless of its size.

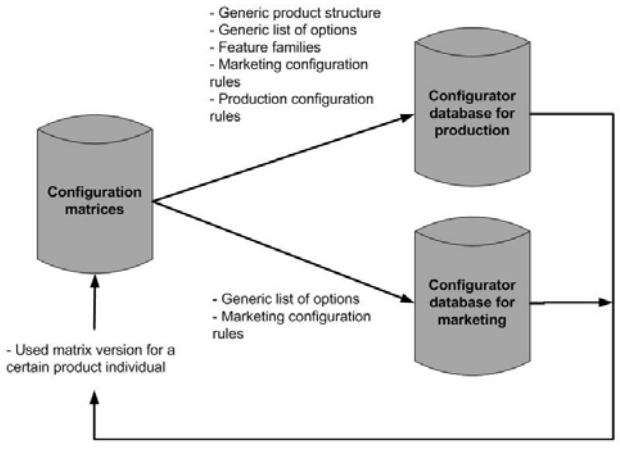


Figure 3. Integration between configuration matrices and configurators

Configurator Design

A typical configuration process (sales/development) according to [2], [10] is presented in Fig.4. The configurable product concept is typically designed by modular product architecture. Less complex models very often have an advantage over large complex models for possible difficulties in communication with customers. A configurable product may be expanded by adding new modules or replacing old ones or by changing the existing customer requirements, which may prolong the life of the product.

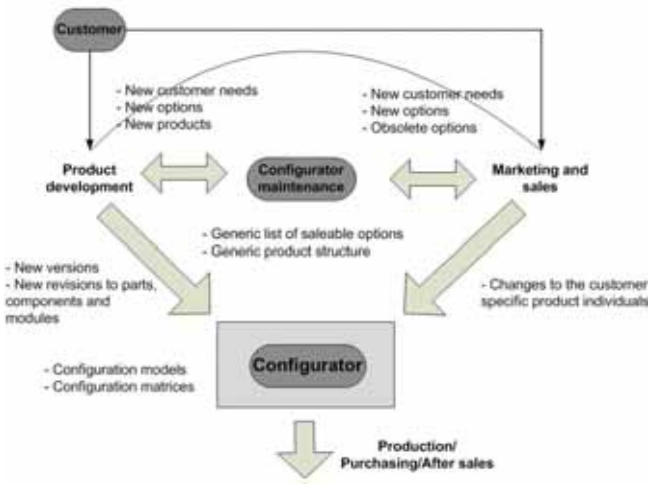


Figure 4. Development/sales process supported by a configurator [2, 9]

The matrix-based configurator may be observed as two wholes (manufacturing and marketing). The manufacturing configurator is used to define the specific manufacturing structure defined by the user. The entire system is fully synchronized with the configuration matrices and if anything needs to be changed in it, it is done via the matrices. After that, the data in the configurator database is updated and it is ready for use. It works in the way that specific manufacturing configuration rules are set up from the configurator database on the basis of a specified offer or a customer order. After this, the rules are compared with

the offer and the order and an iterative configuration selection process is carried out. The database is searched and the data found is saved as a record in the database. It is automatically forwarded to the ERP/PDM/CAD system. The marketing configurator is using the marketing configuration rules. Its task is to configure the specific user options to be used for the configuration of a specific user structure. This whole should ensure the following: respective configuration requirements in accordance with the configuration matrices, cost analysis during the configuration process and the final cost specification for the selected configuration, a visual display of what we selected, of what cannot be selected, and the rejected selections, thus providing the user to go back, reselect what needs to be reselected, and enter a valid configuration in the database.

As presented in Fig.5, the main idea behind a matrix-based configurator is that there is an administrative web interface ensuring that the configuration knowledge about our products is integrated with the organizational ERP/PDM/CAD database and the configuration matrices and automatically performs everything the bases need.

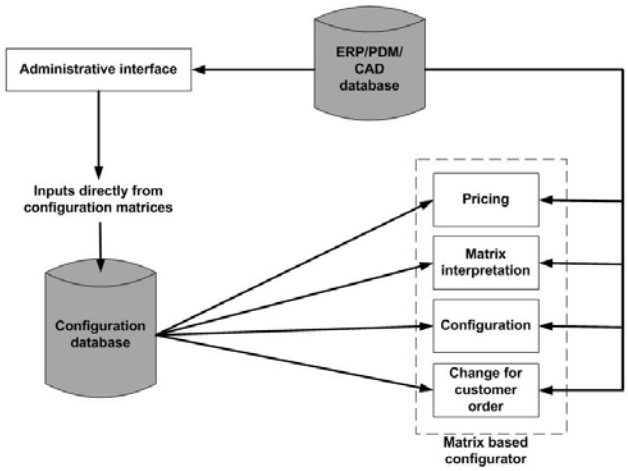


Figure 5. The matrix-based configurator concept

These databases are then used by the configurator and they also use ERP/PDM/CAD bases if necessary. Integration with the ERP system is essential for several reasons. First, we enter specific customer orders in the enterprise's operating system. In addition, the supply time and information from the operating system may be used with the configurator. Integration in PDM may be required for obtaining the configuration model from the PDM system and to save that configuration model. A configuration not saved in PDM may be used as a base for configurator maintenance. An integration in the CAD system may be required if an advancement or geometric arrangement is required during the task configuration.

The selection of an optimal product variant relies on the concept of design domains [11]. Based on such a holistic view [12], product family design and development encompasses consecutively five domains, namely the customer, functional, physical, process and logistics domains. The product family decision making process involves a series of "what-how" mappings between these domains. The customer domain is characterized by a set of customer needs (CNs) representing the segmentation of markets demanding product families and triggering downstream product family design mappings in a cascading manner. The CNs are first translated into functional requirements (FRs) in the functional domain, in which designers take into account engineering concerns and elaborate these requirements based on available product technologies. The mapping between the customer and the functional domains constitutes the front-end issues associated with developing product families. Such a product family definition task is always carried out within an existing product portfolio and manifests itself through these common practices of order configuration and sales force automation. Product family design solutions are generated in the physical domain by mapping FRs to design parameters (DPs) based on the shared product platform.

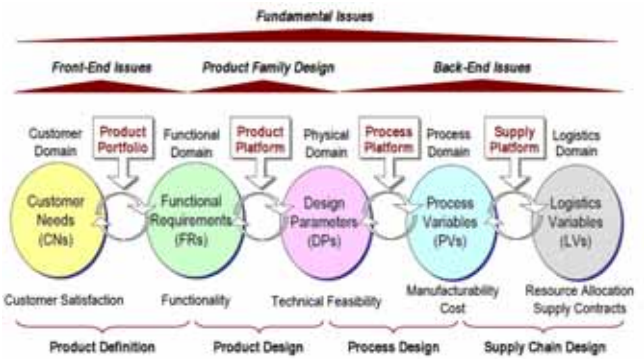


Figure 6. A holistic view of product family design and development

This stage involves typical decisions regarding product family design and configuration. At the front-end, the product portfolio articulates a detailed achievement of customer satisfaction in the customer domain in the form of specifications of functionality in the functional domain. The main focus of the platform-based product family design is the technical feasibility of DPs in terms of fulfilling the specified functionality. The back-end issues associated with product families involve the process and logistics domains, which are characterized by process variables (PVs) and logistics variables (LVs), respectively. The mapping from DPs to PVs entails the process design task, which must generate manufacturing and production planning within existing process capabilities and utilize repetitions in tooling, setup, equipment, routings, etc. Corresponding to a product platform, production processes can be organized as a process platform in the form of standard routings, thus facilitating production configuration for diverse product family design solutions [13].

Case study

Fig.7 shows the interface for an entry of a new project we open in the configurator. In case of failure to enter or an entry of wrong data, the program will notify us and request us to reenter. Fig.8 requires us to enter the input requirements for the product, based on which we will select the desired option. The program is designed in the way that it only offers the selection of possible options – in case of the entry of unrealistic data, it will notify us. Based on this interface, we have a selection of products and we can offer several product variants, after which we decide on the most suitable one with respect to, for example, the product dimensions, weight or type of installation. The configurator lists the selected variant for the selected option, including all relevant data and a photograph, as well as drawings with product dimensions (see Fig.9).

Figure 7. Interface for the entry of information for the project

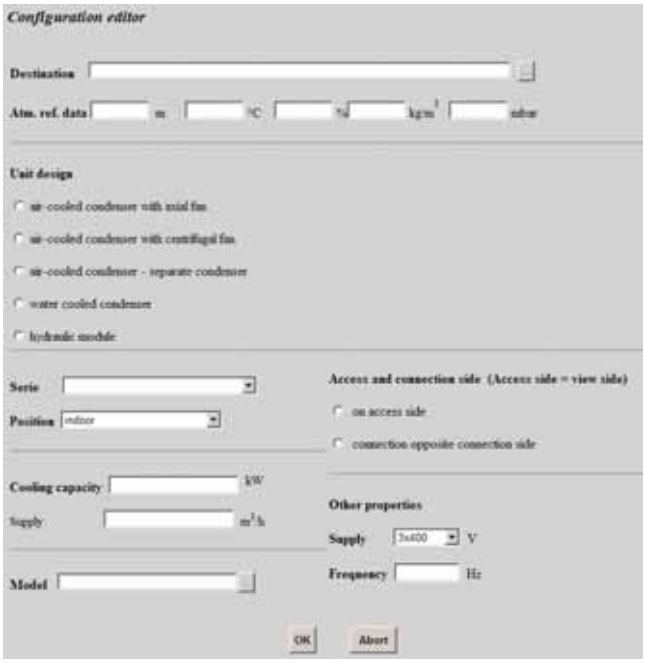


Figure 8. Interface for the entry of requirements

Discussion

The presented approach has several limitations related to configuration matrices. These are:

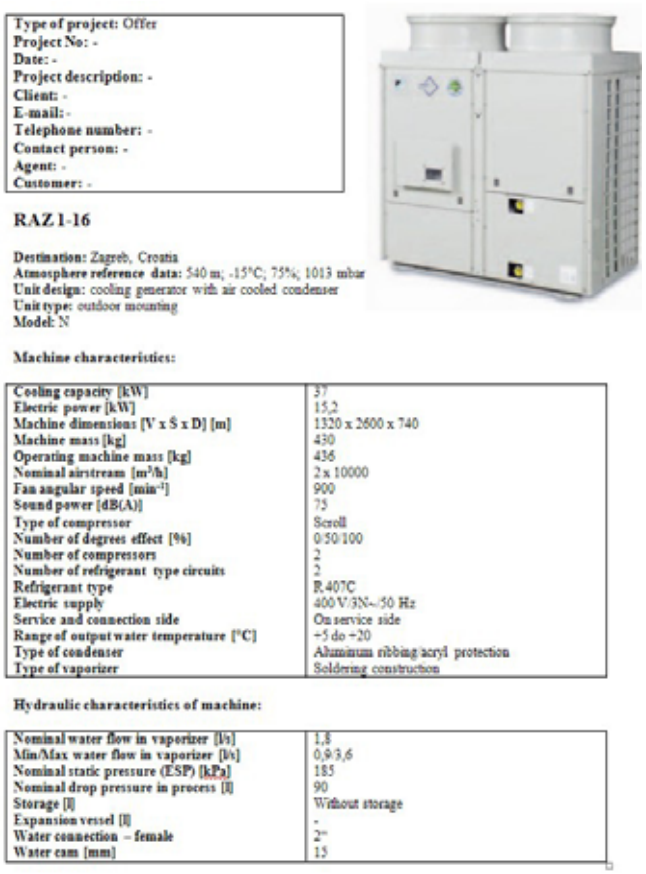
- No numerical data or functions can be part of plain matrices
- Describing module selections with multiple combinations is difficult
- No validity checks when updating configuration matrices
- No combinations between features possible.

The main focus for the use of configuration matrices is to automate the process related to updating the configuration knowledge for the configurator.

Conclusion and Future Research

One of the main objectives of this paper was to find and use a simple method for the presentation of configuration knowledge. The role of configuration matrices in product development is to document modular product structures. They are made after module definition and decomposition of the product function and after the definition of the interface modules and the selection of the product variants. Matrices may also be used for the analysis of product family structures [14]. A configuration matrix may also be observed as an integrating element between product development, manufacture, marketing and sales. As mentioned above, configuration matrices offer a visual tool for configuration knowledge change management. One of the main reasons for the presentation of configuration knowledge in this manner is that it facilitates configuration rule management in cases of changes to the environment, i.e. the configurator ensures sufficient working flexibility. Of course, this is only possible when such changes are not frequent; otherwise, something like this would be almost impossible to achieve. The operating deficiencies occurring here are: presentation of numerical data or functions as a part of the matrices is impossible; it is very difficult to describe the module selection with several combinations; combinations of features are impossible, and it is impossible to validly verify changes to records in the matrix.

Future research may be carried out in several directions: first, the development of a knowledge base for configuration matrices with a defined user interface that would provide configuration matrix updates and further development of the product configurator, including a connection between the features, integration with CRM, capacitive estimates for manufacturing and time analysis, which would use artificial intelligence methods and thus support the design process in all phases. It is also possible to develop a configurator base that could be connected to a CAD program tool, which would generate a 3D product model based on the selected variant.



Type of project: Offer
Project No: -
Date: -
Project description: -
Client: -
E-mail: -
Telephone number: -
Contact person: -
Agent: -
Customer: -

RAZ 1-16

Destination: Zagreb, Croatia
Atmosphere reference data: 540 m; -15°C; 75%; 1013 mbar
Unit design: cooling generator with air cooled condenser
Unit type: outdoor mounting
Model: N

Machine characteristics:

Cooling capacity [kW]	57
Electric power [kW]	15,2
Machine dimensions [V x Š x D] [m]	1320 x 2600 x 740
Machine mass [kg]	430
Operating machine mass [kg]	436
Nominal airstream [m³/h]	2 x 10000
Fan angular speed [min⁻¹]	900
Sound power [dB(A)]	75
Type of compressor	Scroll
Number of degrees effect [%]	0/50/100
Number of compressors	2
Number of refrigerant type circuits	2
Refrigerant type	R 407C
Electric supply	400 V/3N~/50 Hz
Service and connection side	On service side
Range of output water temperature [°C]	+5 do +20
Type of condenser	Aluminum ribbing/acryl protection
Type of vaporizer	Soldering construction

Hydraulic characteristics of machine:

Nominal water flow in vaporizer [l/s]	1,8
Min/Max water flow in vaporizer [l/s]	0,9/3,6
Nominal static pressure (ESP) [kPa]	185
Nominal drop pressure in process [l]	90
Storage [l]	Without storage
Expansion vessel [l]	-
Water connection – female	2"
Water cam [mm]	15

Figure 9. Web form with the selected product

References

[1] SANDERSON,S.M., UZUMERI,M.: *The innovation Imperative – Strategies for Managing Product Models and Families*, Times Mirror, Higher Education Group Inc., 1997.

[2] TIIHONEN,J., SOININEN,M.: *Product Configurators – Information System Support for Configurable Product*, Helsinki University of Technology, 1997.

[3] Peltonen, H., Mannisto, T., Soininen, T., Tiihonen, J., Martio, A., Sulonen, R., "Concepts for Modelling Configurable Products", Publications of Helsinki University of Technology, 1998.

[4] Mesihovic, S., Malmquist, J., "A Process-Oriented Approach for Management of Product Configuration Models", Proceedings of ASME 2004, Salt Lake City, 2004.

[5] Nummela, J., "Matrix Based Method for Maintaining Configuration Knowledge", Proceedings of Nord Design 2004, Tampere, 2004.

[6] Malmquist, J., "A Classification on Matrix based Methods for Product Modeling", Proceedings of DESIGN 2002, Dubrovnik, 2002.

[7] Osman, K., Bojčetić, N., Marjanović, D., "Implementation of Modular Architecture of Cooling Generators", Proceedings of DESIGN 2008, Dubrovnik, 2008.

[8] Erixon, G., "Modular Function Deployment – A Method for Product Modularization", PhD Thesis, KTH, Stockholm, 1998.

[9] Steward D., "The Design Structure Matrix: A Method for Managing the Design of Complex Systems", In: IEEE Transaction on Engineering Management, 1981, Vol. 28, No. 3, pp. 321-342.

[10] Sabin D., "Product Configuration Frameworks – A Survey", IEEE Intelligent Systems, 1998, pp. 42 – 49.

[11] Suh N.P., "Axiomatic Design – Advances and Applications", Oxford University Press, New York – Oxford, 2001.

[12] Jiao J., Simpson T.W., Siddique Z., "Product Family Design and Platform Based Product Development", Journal of Intelligent Manufacturing, 2007, Vol. 18, No. 1, pp. 5-29.

[13] Jiao J., Tseng M.M., „Understanding product family for mass customization by developing commonality indices", Journal of Engineering Design, 2000, 11(3), pp. 225-243.

[14] Sarinko K., Martio A., Huuskonen T., "An Initial Empirical Study od a Using Product Configurator As a Support Tool For Developing Product Families", Proceedings of DESIGN 2002, Dubrovnik, 2004.

Received: 25.08.2011.

Prikaz konfiguracijskog znanja pomoću matrično baziranog konfiguratora

Konfiguracijske matrice se koriste u razvoju proizvoda za dokumentovanje struktura modularnih proizvoda. One nam služe kao vizuelni alat u menadžmentu promena konfiguracijskog znanja, stoga možemo reći da se konfiguracijsko znanje menja istovremeno sa uticajem procesa razvoja proizvoda na postojeće proizvode. Prikaz znanja sa navedenim matricama olakšava upravljanje konfiguracijskim pravilima u promenama okoline. Ovim se pokušalo da se ostvari prikaz koji će biti jednostavnije razumljiv i prilagođen ljudskim sposobnostima. Ovaj rad također prikazuje i matrično bazirani konfigurator, te njegov razvoj.

Ključne reči: **konfiguracijsko znanje, konfiguracijska matrica, matrično bazirani konfigurator.**

Показ настройки знаний конфигурации с использованием матриц на основе конфигуратора

Матрицы конфигурации используются в разработке продуктов для документирования структуры модульных продуктов. Они нам служат как визуальный инструмент в управлении изменениями в знании конфигурации, и поэтому мы можем сказать, что знание конфигурации изменяется одновременно с влиянием процесса разработки изделия на существующие продукты. Показ этих знаний с указанными матрицами позволяет легко управлять правилами конфигурации в изменениях окружающей среды. Это попытка добиться показа, который будет легче понять и адаптировать его к возможностям человека. В работе также показана матрица на основе конфигуратора, и её развитие.

Ключевые слова: **знание конфигурации, матрицы конфигурации, матрицы на основе конфигуратора.**

Présentation des connaissances de configuration par le configurateur basé sur la matrice

Les matrices de configuration sont utilisées dans la développement des produits pour la documentation des structures des produits modulaires. Elles servent d'outil visuel dans la gestion des changements chez les connaissances de configuration et pour cette raison on peur dire que la connaissance de configuration change en même temps que l'influence du processus de développement des produits sur les produits existants. La présentation de la connaissance avec les matrices citées facilite la gestion des règlements de configuration lors des changements de l'environnement. Dans cette recherche on a essayé de réaliser une présentation qui serait compréhensible et adaptée aux capacités humaines. C travail expose aussi le configurateur basé sur la matrice ainsi que son développement.

Mots clés: **connaissances de configuration, matrice de configuration, configuration basé sur la matrice.**