Model-driven data maintenance for configuration systems to tackle the challenges of mass customisation and organisational forgetting with focus on the aviation industry

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Abstract: In past century, a transition from craftsmanship production to standardisation production has taken place. An approach to combine both methods is mass customization, which needs to be supported by accurate IT Systems, in fact configurators. The main objective of a configuration system is to digitise knowledge and automate tasks. This contribution elaborates a model-driven approach for configuration data maintenance which can be intuitively used by the domain experts and is powerful to cope with complex domains like aircraft industry. Within Airbus, a project based on this approach was awarded the renowned "Airbus Awards for Excellence 2008" in the category of innovation.

1 Introduction: Mass Customisation

In the past century we have seen a transition of production methods in many industries from a pure craftsmanship approach to a standardisation approach. In their most extreme occurrence both approaches are characterised by the following properties:

Craftsmanship	Standardisation
• Every product is unique, custom-made • High degree of individuality, high level of customizability • Usually very high vertical range of manufacture • Very cost-intensive engineering manufacturing, marketing • No leverage of positive scale-effects • Suitable for high-end products with a high level of specialization or products with a high degree of monetary or emotional value	• Every product is the same • No individuality, no customizability, products off the shelf • High degree of re-use, use of standard components, supply chains etc. • Cost-efficient engineering, manufacturing, marketing • High leverage of scale effects • Suitable for bulk-products with low degree of variance/individuality and/or low level of monetary/emotional value

An approach trying to combine both worlds is *Mass Customization*. The term was coined by STAN DAVIS [Da96] describing a situation "when the same large number of customers can be reached as in mass markets of the industrial economy and simultaneously they can be treated individually as in the customised markets of pre-industrial economies".

However, while mass customisation promises to offer the advantages of both standardisation and craftsmanship approaches, it comes at a cost:

- A costly variant management is necessary (product / variant modelling, appropriate data etc.)
- Change management processes are necessary
- Strategic change in production / planning / marketing / sales /after-sales processes is needed
- Use of tools (PDM[1] /PLM[2], product configurators) is necessary to allow for an efficient handling of re-usable variability in order to profit from the advantages of mass customisation

[1] Product data management
[2] Product life-cycle management

2 Challenges in the aircraft market today

Since the early 1990's, the market competition in the aircraft industry has remarkably intensified despite the small number of enterprises in this industry sector. Especially in the area of long range (LR) aircrafts, a heavy battle for customers has evolved. The reasons for that have been the rising demand elasticity and the constantly decreasing mark-ups. Additionally, the severe limitations of governmental subsidies as a result of the agreement between the US and the EU in 1992, leaded to an increase of marginal costs of estimated 5%, which intensified the competition as well [DP04].

The problem was tried to be tackled by introducing new types of aircrafts and a leveraged number of options. Even today, the aviation industry is suffering from the situation that the number of different aircraft variants is constantly increasing. This is due to the fact that customers more and more demand for a high degree of customisation with respect to cabin layout and system configuration. While the cabin configuration still needs a large amount of manual design and drawing work in order to create a solution that satisfies the customer, a suitable system configuration on the other hand is already much more based on modularised and standardised components that can be taken as building blocks to set up a complete system – a mass customisation approach.

Such an approach needs a lot of expertise of the employers in the enterprise. However, the aviation industry traditionally and exceptionally suffers from a problem that is known as "organisational forgetting" [Be00]. Due to the high turnover volatility, there is a high fluctuation in the set of employees in these companies. Aircraft manufacturers see a large portion of their labour force as variable, which is highly critical if their knowledge is stored in their heads only. When employees leave the company in times of weak turnover, they take their experience and expertise with them. When the company rehires in time of high turnovers, quite often other people join the enterprise with far less experience. As an effect, the competence of the enterprise is "forgotten" and this due to temporary fluctuations in turnover and a lack of externalised knowledge. The resulting decrease of productivity can lead to severe loss in market shares in comparison to competitors.

3 Solution: Externalised knowledge in a configuration system

A key to improve the situation is to externalise knowledge and to make it automatically processable. This can be achieved by the use of configuration systems:

- Product knowledge is formalised, digitised and made available in a central archive. Thus it becomes much more independent from the problem of organisational forgetting. New employees can find all the knowledge about the product in a central and structured way.
- The configurator can provide the opportunity to automate and accelerate tasks also for complex products that stem from a large variety of product types. This functionally is needed for example when offers for customers shall be created in a short time that want a technical and price information for a bunch of aircrafts in a fleet. Thus, the "mass customisation" approach is realised.

However, a configurator can only provide these benefits if its underlying database contains the product structure and the dependencies in a complete, consistent and up-to-date manner. This fact often obstructs the introduction of configurators in the aviation industry, which leads to the fact that today there are still enterprises that store this mission-critical data merely in the heads of their experts or within unstructured documents (Excel and Visio files, Word documents, emails). The problem of "organisations forgetting" is then a very present one. Therefore, dependencies are not explicitly written down in a formal and commonly understandable manner, but often proprietary diffuse representation forms are used. Moreover, there is typically not only one person responsible for data maintenance. Rather, the data is maintained in a team of several experts, each responsible for one part of the whole domain.

As a consequence, the maintenance of formal product data for a configuration system is a very costly task for enterprises in the aviation industry since there is a huge gap between the level of data formalisation for the configurator and the existing maintenance processes and informal representation models of the data managers.

Since these building blocks are typically dependent from each other and these interdependencies can be formalised in rules, software-based configurator systems based on precise Boolean logics can help automating many of the necessary tasks that would be very time-consuming and error-prone when done manually:

- A configurator is able to check whether a given aircraft configuration is correct (i.e. compliant to all dependency rules).
- A configurator is able to calculate the consequences if a given aircraft configuration shall be changed (e.g. upgraded with a certain system).
- A configurator is able to organise a large number of aircrafts into groups that behave similarly regarding a certain operation (e.g. a system change). This enormously helps reducing the time needed to answer customer requests regarding a whole fleet as only one representative of each group of aircrafts has to be analysed.
- A configurator can calculate the technical specification that is the basis for a commercial offer.

4 State of the Art

The main drawback of today's configurators is their predefined data model for representing the structure and the dependencies of a customer's product. Although a large plethora of different modelling approaches exist (e.g. table-based representation of dependencies, graphical representation of Boolean rules, textual representation of Boolean rules etc.) and even some "standardised" approaches for configuration data modelling are available (e.g. [Fe07], [Hü05a]), especially for very complex products and the special business operations required on them, individual data modelling approaches are inevitable. With today's products on the market, data maintainers are often forced to strongly adapt their existing product structure and modelling paradigms behind it into the pre-defined formalism of the configuration system. This leads to an unintuitive and hard-to-grasp maintenance approach, resulting in errors and time-consuming testing quality

assurance procedures. Especially in the aircraft industry, still a lot of standard configurators can be found, although the paradigm of how to structure the build-up of an aircraft follows a very unusual and specific approach using EPACs[3] and TDUs[4] that is especially patented in the avionics industry [Hü05b].

5 A model-driven approach with CAS Configurator Merlin

With CAS Configurator Merlin, its flexible data maintenance module CAS Mermaid and the large knowledge that we have in the area of complex data maintenance for configurators in the aviation and automotive industry, the above mentioned problems can be solved. By that the full power of a configuration system can be revealed. We achieve this by applying an innovative *model-driven data maintenance approach* (see overview in Figure 1). This means that in the beginning a customer-specific formalism (or language) for the representation of the products and the dependencies is defined. This *high-level model* is set up together with the data administrators and the resulting formalism is close to the informal models that they use today (e.g. directly using terms such as EPAC/TDU or 2-letter programme abbreviations like "LR" that are common in the aviation industry), but with a defined and clear semantics. Typically, a graphical representation of the dependencies within the products is advantageous since a high-level model can be used more intuitively and is understood more quickly by the data administrators. The formalism of the model forces the data maintainers to be precise and to externalise hidden knowledge into the system. Data administrators use a graphical editor to edit and check product dependencies in the high-level model. All models are stored in an archive database that is centrally accessible by all data administrators. Beside the current version of model, it also contains previous versions to be able to restore an old state.

[3] EPAC = Entity per Aircraft
[4] TDU = Technical Description Unit

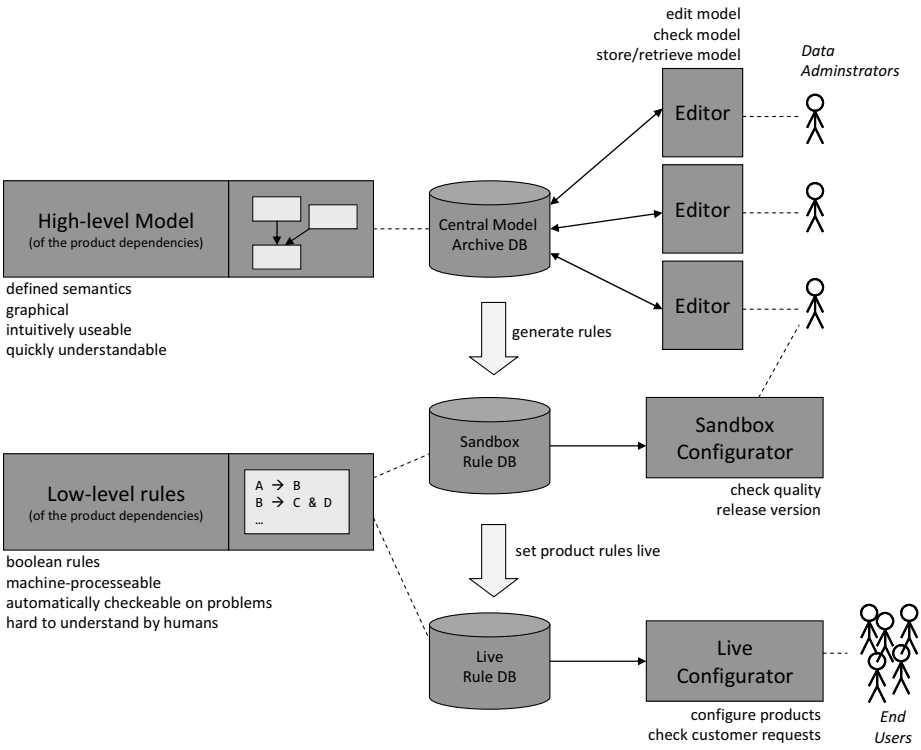

Figure 1: Model-driven rule maintenance process

The high-level model documents can be used to automatically generate a set of formal Boolean rules that can be directly processed by the configuration system. No expert has to write cryptic formulas which can become very confusing and error-prone. On the one hand, rules can be put into a sandbox rule database that is attached to a sandbox configurator. This is only internally accessible and can be used to check the consistency and quality of the created rules. After the release of a rule set, it is set live and copied into the live rule database, which is connected to the live configurator. This configurator is accessed by end users who use it to configure their desired products (in this case the end users are airline customers) or to check if customer requests are valid (in this case the end users are engineers or sales people).

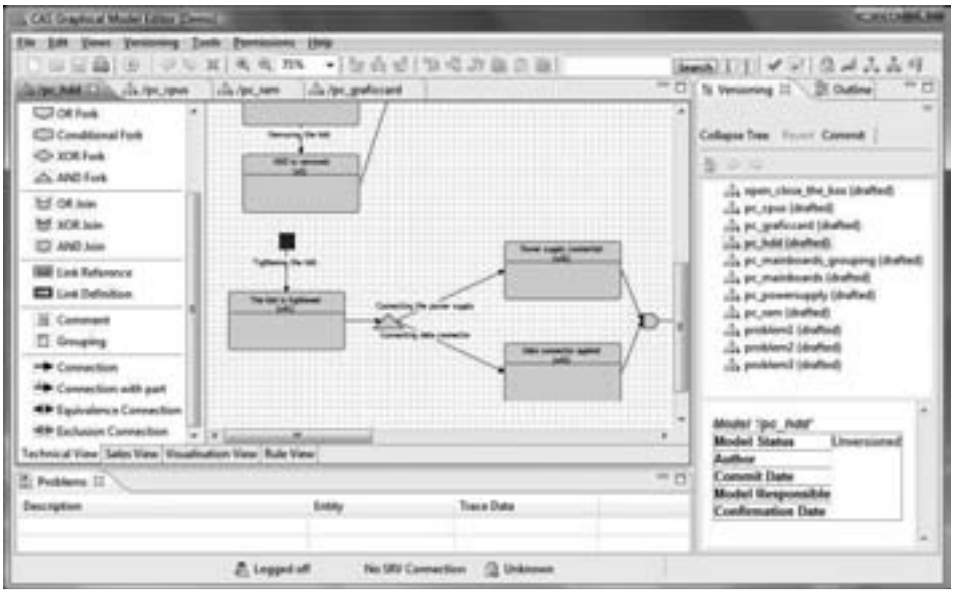

Figure 2: Screenshot of possible editor application based on CAS Configurator Merlin Maintenance.

Figure 2 shows a screenshot of a possible editor with an example of a customer-specific modelling language. On the left-hand side, the palette of modelling operators is visible: generic Boolean operators such as OR, XOR and AND, but also more customer specific operators such as "Connections with parts" or "Conditional Fork". In the centre of the image, an extract of a product model is shown based on those customer-specific operators. Here, an example for configuring a PC is shown. On the upper, right-hand and lower borders of the application, the standard functionality of the editor is visible. It offers functions such as saving, loading, versioning, rights management, search, printing, model checking, outline and problems view independently of the customer-specific modelling language. Technically, the editor is based on the Eclipse Rich Client Platform (RCP) and makes use of the modularisation approaches of the underlying OSGi framework. This allows creating a customer-specific bundle that represents the modelling language, palette and editor, which can be flexibly plugged into our standard framework.

6 Advantages of a fully integrated configurators

This externalised knowledge has many advantages for the enterprise:

- As the knowledge is formalised and made available in machine-readable form, it can be stored in a central archive, versioned, analysed on version differences, but also printed and put into presentations. Thus, working in a team of experts on these externalised knowledge documents becomes very effective.
- New employees can find all the knowledge about the product in a central and

structured way.

- Domain experts can use the configurator to check their high-level models for syntactic, logical and semantic correctness. By that, errors in the models can be found in an early stage and in an automated manner.
- Working with formal documents to describe product dependencies allows setting up a sophisticated and multi-staged clearing process. Newly created or changed documents have to pass several quality gates until they can be activated in the live system.
- With these formal rules, the configurator can provide the opportunity to automate and accelerate tasks that are needed for example when creating offers for customers that want a technical and price information for a bunch of aircrafts in a fleet.

7 Summary

Especially in the area of aviation, there is still a large potential for the configuration of aircraft. With CAS Configurator Merlin and its model-driven approach, the necessary data maintenance process, which is normally feared to be very complex, time-consuming and error-prone especially when done in a group of experts, becomes understandable, transparent and in the end manageable for the experts. On the one hand, this helps externalising the core business knowledge of dependencies within aircraft in a centrally available archive instead of in the heads of the experts. On the other hand, generating formal rules from these documents provides the possibility to make use of the automatic processing capabilities of a configuration system. These can be especially interesting for creating technical and commercial offers in a quick and error-free manner.

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