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How to scope a product configuration project in an engineering company

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Abstract: *When implementing a product configuration system in a company making complex and highly engineered products, many decisions need to be made in the early phases of the project. This article presents a framework for supporting the initial scoping process and discusses experiences from applying the framework in an engineering company. The framework covers a number of topics, such as identifying the users of the configuration system, prioritizing the user requirements, defining the input and output, and the overall functionality of the configuration system. Furthermore, the scoping process considers the availability of the product knowledge to model into the configuration system, the level of detail and which particular product parts and aspects to include in the system.*
Key words: ***Configuration Systems, Product configuration, Scoping, Level of Detail, Early Phases***

1. INTRODUCTION

Improving the quotation process by the help of configuration systems is a huge opportunity for enhancing presales and production process efficiency in companies. Furthermore, configuration systems can be applied to support the decision process and to illustrate the possible product alternatives [1]. The scope of most of the work done in the configuration conspectus has been very limited and specialized, as stated by Tiihonen [2]. However, in early phases of the configuration project decisions are made which are very important for the success of the entire project. This means that both the structure of the product and the cost estimations are influenced by the content of the configuration system.

A product configurator is a subtype of software-based expert systems or knowledge-based systems with a focus creating product and process specifications [3]. A configurator supports the users in specifying the product's different features by confining how predefined entities (physical or non-physical) and their properties (fixed or variable) may be combined [4]. At the early phases of a configuration project, it is often difficult to identify and retrieve the right information to be implemented in the system. Collecting and discussing product knowledge from product experts helps in finding robust modelling solutions which meet the desired quality. A number of strategies dealing with this challenge have been proposed in academia, such as the Product Variant Master (PVM) by Hvam et al. [12] and the Product Family Master Plan by Mortensen [15]. However, modelling products with high complexity, e.g. due to the variety of outputs expected from configurator and integrations to other IT systems, is still challenging. Additionally, configuration engineers often lack experience in specific technical areas of a product and thus have difficulties in implementing the relevant aspects of it.

Problem statement: The present paper addresses the challenge of modelling complex and highly engineered products based on a practical example of a configuration project for an entire production plant. A major challenge in configuration projects of this type is to find a way of retrieving knowledge that is based on deep technical experiences, establishing a quick overview of various engineering areas, and creating a satisfactory level of analysis and communication. Therefore, a configuration engineer has to ask for and combine information which is relevant but often out of his expertise. Due to this lack of overview, companies spend a considerable amount of time and resources on retrieving, filtering and processing the information to be modelled in the system. Yet, as companies are under time and resource pressure in their sales and pre sales processes, they are challenged with high costs and resources on tasks which are not creating much value and which could otherwise be spent on research and innovation. Organizations are typically aware of the opportunity to limit non-value adding activities, but often lack the methodology to address it properly. Activities in quotation processes involve people with different expertise from different departments, provoking problems in communication and overlapping skills. As a result, engineers are spending a relatively high amount of their time on coordination and waiting for feedbacks. Working in such a company makes it easy to observe the difficulties encountered in a real case; e.g. when engineers spend the majority of their time just to maintain and update thousands of widespread documents that are used for the quotation process. Each of these documents belongs to different people with different backgrounds and is supposed to contribute to a specific proposal when a quotation is made for a particular order. We believe that in such a case the solution is to use a unified configuration system which documents the required product information.

2. LITERATURE BASE

Using a standard framework such as the Rational Unified Process (RUP) as an iterative process helps engineers to perform their tasks professionally in early phases of the project and to develop and test their solutions in short life cycles. The RUP methodology includes different tools that empower engineers to learn and work independently. The RUP is a software development process which contains many of the modern development techniques and approaches such as: object technology and component based development, Unified Modelling Language (UML), architecture modelling, iterative development cycles to verify the model quality etc. [5]. According to the iterative development principle, the whole system is frequently tested so as to address the risks of modelling in early stages of configuration projects [6]. In complex and highly engineered products with high connectivity of components and many constraints, early tests and mistake preventions are vital for keeping the development costs at a reasonable level. However, generic development methods, such as the RUP, are not necessarily suitable for every type of project but require content specific adjustments [7].

A. 2.1 Previous research on configuration projects

Literature suggests that various benefits can be derived from the use of configuration systems. L. Hvam et al. carried out four empirical case studies and listed some of the significant benefits [8]. Ladeby and Oddson define the total configuration system (TCS) as the configuration system including the business context in which the configuration system operates [9]. Forza and Salvador define a configuration system as the “set of human and computing resources” needed to “accomplish configuration and modelling processes” [10]. Blecker considered the advisory system as an independent software system. The configurator contains the product model, whereas the advisory system takes over the consulting role [11].

As illustrated in *Table 1*, only few researches have focussed on how to scope configuration projects in the initial phase of a project, define the input and output of the system, clarify the modelling details, and describe the interaction with the stakeholders.

Table 1. *Approaches to configuration projects*

Concepts / Publication	1. Aims and purposes of the configuration system: Configuration Systems Benefits	2. Stakeholders’ requirements	3. IT structure: Input/ Output Managing and UI	4. Products’ features: updating and maintenance	4. Products’ features: Level of details	5. Project plan: RUP	5. Project plan: Modelling techniques
Hvam et al. [8,12,19,22]	X			X		X	X
Forza et al, 2002[13]			X		X		X
Salvador et al, 2004 [14]	X						
Mortensen et al. 2008[15]	X	X					X
Haug et al. [16,20,21]			X	X		X	X
Ladeby et al, 2011 [9]	X						
Blecker et al, 2004 [11]	X						
Tidstam et al, 2010 [17]							X
Jannach et al, 2013, [18]			X	X			
Dvir et al, 2003 [23]		X					
Felfernig et al, 2000 [24]						X	
Trentin et al, 2012, [26]	X						

3. RESEARCH METHODOLOGY

The research aim is dedicated to scope the development procedure of the configuration systems as a general concept. We use an empirical case to define and validate a general process, from information gathering and tools introduction to the maintenance part. This allows us to contribute to both theory and praxis. Aligned with the overall objective, the research has been structured into two phases. The first phase is concentrating on the most efficient process according to the investigations. To test the introduced process on a real case, the second phase is emphasising the practical aspect of the research.

B. 3.1 Procedure development

This phase is considered to introduce all available tools, combine them on a specific case and educate the engineers as to how to use them. To identify the case-specific obstacles, the procedure has been developed by the researchers working directly in the industrial environment and in closed dialogue with product experts.

C. 3.2 Reporting the process efficiency of a real case

Providing feedback from real cases and supplying the process with suggestions for creating functional effectiveness offers a great opportunity to achieve empirical validity. Hence, the framework has been tested in a company as a realistic situation for complex and highly engineered products. The major challenge was to find a way to configure an operation which is extendible to all other projects. The process was tested for at least one month, and the results have been completely accepted by the organization.

4. HYPOTHESIS DEVELOPMENT

Based on the theory presented above we suggest that a scope for a configuration system should include:

1. Aim and purpose for the configuration system and overall process flow [12, 25]
2. Identification of stakeholders and their requirements [22, 12]
3. IT-architecture incl. flow in the configuration system, UI, input, output, integrations, and main functionality of the configuration system [2,27]
4. Products and product features to include in the configuration system, incl. level of detail [12]
5. Project plan incl. resources, time table, modelling approach, test and development, system maintenance, etc. [23, 28, 26, 29, 30, 21, 31, 33, 34, 1]

4.1 Aims and purpose of the configurator

This part will discuss the overall aim of implementing the configuration system.

1) 4.1.1 Vision of product configuration projects

The vision states the purpose of implementing the configuration system. What aims should the configuration systems follow? As an example the vision to use a specific configuration system could be less time and resource for introducing a new system and fewer errors in the implementation process. Configuration projects can in general be divided into two major categories with each having a different vision. The first category is performing presales or the commercial process, and the second one is configuring the sale and production or technical process [10].

2) 4.1.2 Objectives and gap analysis

Besides the vision, additional operational objectives can be listed such as [12]:

- Lead time reduction for product customization and document generation
- Less resources consumption for producing specifications
- Higher quality of specifications
- Quality improvements in quotations
- Higher independency from product experts
- etc.

When the objectives of the configuration systems have been formulated, the next step is to carry out a series of measurements in relation to the individual targets. When the targets and the current performance are known, they are summarized via a so-called gap analysis [12]. For example, if the lead time for the current situation is 7 days and the target is 2 days (the aim of the project) it means that a 75% gap or reduction in the lead time is intended.

3) 4.1.3 Process flow

The purpose of this part is to have a standard definition of the current and future flow of business processes.

AS-IS and TO-BE flowcharts: an AS-IS flowchart shows exactly the current situation of the company and the complications of the process. According to the company requirements there will be a number of scenarios for the future process. The TO-BE flowcharts can be drawn according to these scenarios. As an example, the configuration system could have different purposes from varying product perspectives [25]: make to order, configure to order, engineer to order, or integrate-to-order.

4.2 Stakeholder requirements

Stakeholder requirements are a wish list from different type of users to be considered in the subsequent steps. One of the reasons for having a strategy in the first phases of the project is to support the prioritization of individual stakeholder requirements. It is important for the further development that all stakeholders are identified along with their use patterns. This is necessary in order to prioritize functions and interfaces of the configuration system [22].

4) 4.2.1 Stakeholder identification

Stakeholders could be among different groups of people such as sales staff, product developers, production staff, marketing staff etc. with different requirements to the configuration system.

5) 4.2.2 Requirements

These are some examples of stakeholders' requirements in different sections: language variety, currency variety, online functionality, required output documents, and different user interfaces (UIs). The stakeholders and their necessities can be drawn through two specific methods: the first one is by using process flowcharts (TO-BE process), and the second one is by utilizing the use case diagrams from the RUP method [5]. A use case is a pattern for a limited interaction between a system and actors in the area of application. Use case diagrams are the means of expressing the requirements and the actors involved in the project. According to the RUP rules the same use case is utilized in system analysis, design, implementation and test. Note that an actor can be a person or an IT system which delivers and fetches information from the system. It is vital to develop the system aligned with the user requirements. Thus, it is important to describe the actors and their desired use cases. An actor is a role that includes users or other systems that have the same use patterns [12].

D. 4.3 IT-architecture

IT architecture is addressing the structure and techniques of the configuration system. RUP covers almost all aspects of a typical software development project. The IT architecture has to include:

- Definition of the configuration system,
  a) Inputs, Outputs
  b) UI
- Main functionalities such as online and offline functionality
- Decision flow in the configuration system
- Specification of integrations with other systems in the company such as ERP or the calculation systems.

E. 4.4 Products and products' features

1) 4.4.1 Which products and which product features to include in the model?

In order to limit task for registering the knowledge during the life cycle of products it is useful to consider the product range from four different points: product structure, product functions and properties, product life cycle properties, variation and family structure [12].

2) 4.4.2 Level of detail to include

Having described which products and product features to include, the next step is to define the level of details to include in the system. This detail management will help us save a lot of time and resources. There are always a number of questions about the level of detail in the configuration systems, while it is not easy to answer which aspect of a product should be taken into consideration. If no specific management strategies are used in early phases for controlling the details, the impact on the performance and business will be enormous. The technical and business aspects are:

- Further complexity in the configurator
- Difficulties in data documentation, updating and maintenance
- Facing lack or additional data when generating documents
- Integration problems
- Difficulties in communicating with domain experts
- Spending a lot of time and resources on gathering irrelevant additional information
- Spending a lot of time and resources on asking questions because of the deficiency of knowledge or misunderstandings.

After all, when a configuration engineer is gathering knowledge, he is the one who should know what is needed according to the requirements and vision of the configuration system.

F. 4.5 Project plan and modelling approaches

1) 4.5.1 An introduction to Unified Process

The Unified Software Development Process or Unified Process is a popular iterative and incremental software development process framework. In fact, it is not simply a process, but rather an extensible framework which should be customized for specific organizations or projects. The RUP is similarly a customizable framework. On the time axis in Fig. 1, RUP divides a project into the following four phases: Inception, Elaboration, Construction, and Transition [28]. In this stage, the modelling approaches are including methods and strategies such as:

1. Product Variant Master
2. CRC Cards
3. Testing and development
4. Documentation and maintenance
5. Stakeholders' identification with use case diagrams
6. Iteration process for each component
7. Component based development
8. Project planning

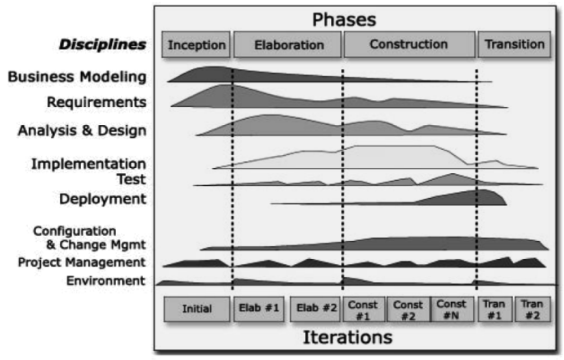

Fig.1. Unified Process [26]

Number 1 and 2 in Fig. 1 are purely product configuration modelling techniques, while number 3 to 7 are related to the RUP methods, and number 7 is the project planning techniques containing some tools that are to be fulfilled for any project. It is also possible to find the obstacles for the project in the risk analysis. For a configuration project a risk could for example be complications in the modelling of products or during programming. According to Kruchten (1998) many decisions related to an iterative lifecycle are driven by risks; and for effective decisions a good understanding of the risks and project faces, and afterwards clear strategies to deal with them, are required [5].

2) 4.5.2 Product Variant Master

The major step is to find the most efficient and structured modelling tools such as the PVM [29]. The purpose is to understand the product hierarchy and ensure that all the people in the company have a common view about the product structure, variants and constraints.

3) 4.5.3 CRC Cards

The detailed information about the product is included in the specific cards called CRC cards. CRC stands for "Class, Responsibility, and Collaboration" and these cards are used to define classes, including the class' name, their possible place in a hierarchy, together with a date and the name of the person responsible for the class [12]. In addition, the class' task (responsibility), the class' attributes and methods, and with which classes it collaborates (collaboration) are given [30].

4) 4.5.4 Testing and development:

Testing is included in the iteration template, and it is as critical for configuration projects as other IT projects. It is seen as an iterative process which enables early feedback in the early phases of the project. The test work flow will help to measure the project quality and defects, and it will omit unnecessary budget for debugging processes at the end of the project. Feedbacks from users help to go in the right direction and learn a lot in the early phases of the project. Testing the project step by step makes the debugging procedure easier for both the tester and engineer.

5) 4.5.5 Documentation and maintenance

Documenting of the system is the most critical tool for establishing a strong communication with domain engineers during and after the project. The suggested documentation system is based on the RUP methodology and modelling strategies, including the Product Variant Master method for modelling product families [12]. The fact of not having a documentation system that supports the modelling techniques means that different software must be applied throughout a project [21]. Avoiding errors and continuously updating the system is crucial for avoiding failure and for getting an acceptance of the system. So the expert cooperation with the configuration team will be necessary, especially for the highly engineered products.

6) 4.5.6 Use case modelling and diagram

Use cases are the means of expressing functional requirements which are understandable by stockholders. Use cases create a design model which could define the test cases and plan the iterations. Scenarios are the instances of use cases which are applied for TO-BE processes in a modelling technique demonstration. Each use case is described in detail, and the use case description shows how the system interacts step by step with the actors. The same use-case model is employed during requirements capture, analysis, design, and test [31].

7) 4.5.7 Iteration process:

If a project is too big and has a long schedule, it often seems to have been bound to fail in most companies. Therefore, we have chosen to split this case project into smaller projects. Each phase in the RUP can be further broken down into iterations. Iteration is a complete development loop resulting in a release (internal or external) of an executable product, i.e. a subset of the final product under development which grows incrementally from iteration to iteration to become the final system [32]. Some benefits from the iteration process in comparison with the waterfall method are: reusing the system, learnings during the project and better quality and management. Figure 1 demonstrates the possibility of planning a general iteration loop for configuration projects.

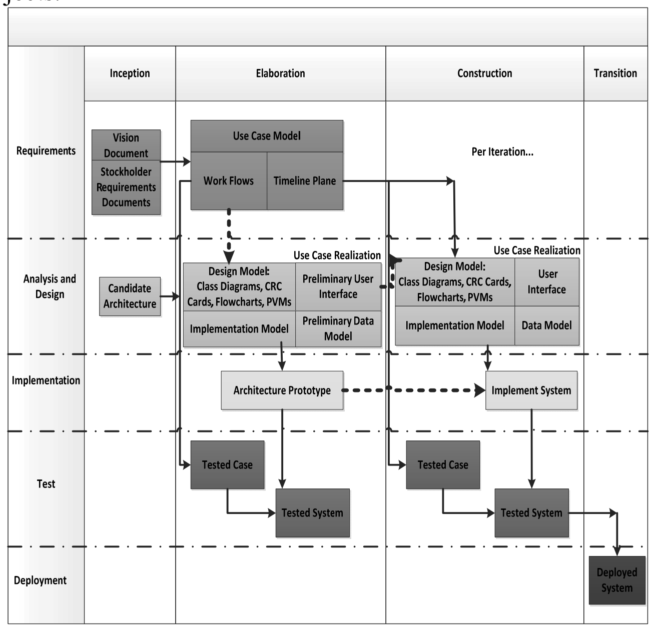

Fig. 2. The general iteration process template for configuration systems

8) *4.5.8 Component-based development:*

Component-based development is about how to build quality systems that satisfy business needs quickly, preferably by using parts rather than handcrafting every individual element [1]. For a highly engineered and complicated product the best way is to split it into smaller components and then follow the iteration loop every time and test it. It makes the project less complicated and allows the delivery of the product to happen as soon as possible.

9) 4.5.9 Project planning

In general, it is possible to have two different plans. The first one is a coarsely project plan with all start and end dates of all phases and iterations. The second level of the project plan is a detailed plan for all iterations [28]. Each phase of the project plan should have a specific responsibility. As an example in the development phase the following roles could be required: the project owner, the project manager, facilitator, the change manager, end user, model manager, process manager, domain experts, and programmer [12]. Every project is a special task, making it difficult or even impossible to plan all the activities at the initial planning phase [32]. Although would argue that too much planning can curtail the creativity of the project workers [33] and others who propose to do milestone planning instead of activity planning. There is no argument that at least a minimum level of planning is required [23]. In fact, planning is considered a central element of modern project management. There are very important aspects to be manifested in the project plan such as: resources for the project and their responsibilities, timing tables, milestones, proposals, deliverables, success criteria, risk estimation etc.

5. CASE STUDY

G. 5.1 Aims and purpose for the configuration system

This article is based on the empirical data collected in collaboration with an international company specialised in the production of heterogeneous catalysts and the design of process plants based on catalytic processes. The Wet Sulphuric Acid (WSA) process is backed by more than 25 years of commercial experience and has proven its value in industries like oil refining, coking, coal gasification, and viscose fibres. A main challenge for the WSA section in the case study is the pre-sales procedures, where a long time (more than 1 week) is needed to accomplish the current situation (more than enough resources), and they cannot overtake their competitors. The regional offices all over the world are not capable of making the quotations themselves because of the amount of the complexities

1) 5.1.1 Vision

The purpose is to introduce a configuration system which can act as a knowledge management system, provide an easy access to product information and offer a simple way of customization. The system will reduce the lead time for generating quotation for sales people and act as a presale technical configuration system [10].

2) 5.1.2 Objectives

The main purpose of implementing a configuration project is to make the sales process more effective. The system empowers salesmen to act more independently from technical experts. By using product configurators to support the engineering of the custom tailored plants, the company is automatically forced to work on modularizing and standardizing the machines in the plants. To engineering companies making complex and highly engineered machines and complete factories a significant challenge remains how to develop and describe modules on a high level of abstraction that may be used in the early phases of the engineering processes. Hence in this project the use of a product configurator will lead to:

• Reduced lead time in sales and engineering processes
• Improved quality of machines and plants
• Increased sales – as it gets easier to generate quotations
• Reduced complexity of the machines and factories
• Cost savings in sales, engineering, production and installation due to the use of product configuration and more well defined and standardised modules in the projects
• Improved accuracy in the cost calculations and a decrease in projects that go over budget

3) 5.1.3 Current situation and future scenario (AS-IS and TO-BE)

In order to describe future scenarios it is necessary to have a comprehensive overview of the current situation. Sales people are currently using excel sheets and a complex homemade calculation system as the main foundation for the creation of technical proposals. The calculation system is a way of calculating the complex chemical process. Another problem is that the time spent on generating a quotation is not competitive in comparison to other companies around the world. The purpose of the project is primarily to create a stable tool aimed at generating proposals with as few errors as possible. The accepted scenario has been shown in the flowchart in Figure 3 below.

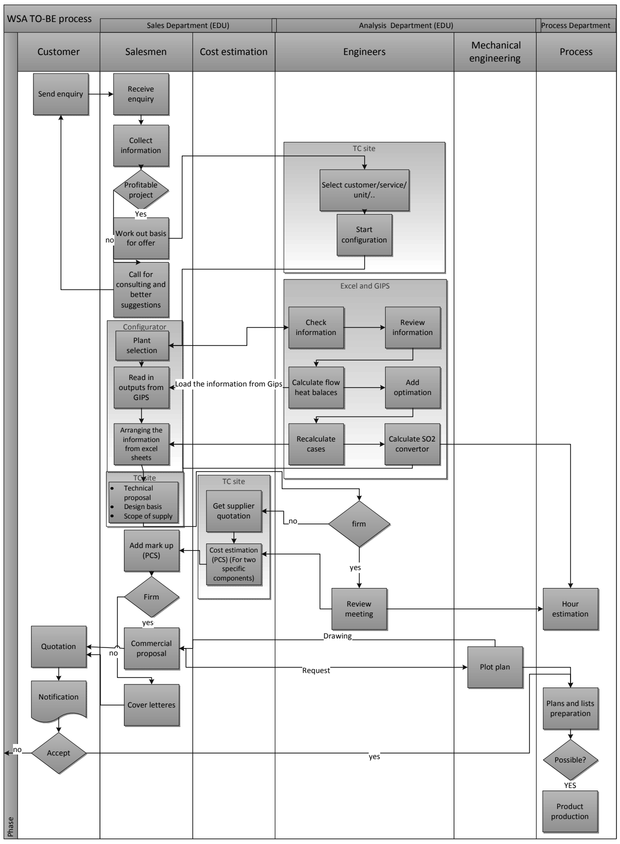

Fig. 3. TO-BE process

H. 5.2 Stakeholders' identification and requirements

In this case, the stakeholders are sales staff, cost estimators, product developers, marketing staff and regional offices with different requirements to the configuration system. The aim is to find a way to integrate the complicated calculation software into the configuration system and make it easier for sales people to get involved in the calculating process. The specific tasks expected to be done during configuration project are:

- ➢ Developing a configuration based on feed stream properties and requirements to the emissions of a specific plant type (all stakeholders).
- ➢ Combining document snippets into full technical or commercial proposals (sales people and cost estimators)
- ➢ Loading data from the configurator into tables in the technical and commercial (sales, cost estimators and marketing group)
- ➢ Price calculation, bills of material and scope of supply (all stakeholders)

- Integration with high performance calculation systems and other systems for receiving the calculated outputs and flow diagrams (all stakeholders).
- User friendly and independent solution (all stakeholders)
- Currency and language versions (regional offices)
- Online based and saving functionality (sales)
- Maintenance and updating the system (sales people and product developers).

I. 5.3 IT-architecture

1) 5.3.1 Inputs/ outputs

Outputs are in need of inputs and have been determined in the TO-BE process and case diagrams. The inputs and outputs examples in this case could be: the size and volume of the components, the entrance or exhausted pressure and temperature, the number of tubes in a condenser, and the number and size of beds in a converter.

2) 5.3.2 Main functionality

The configuration system aligned with this specific case study defines some functionality:

- Capacity dimensioning for the entire plant
- Cost estimation of the machineries
- Needed engineering hours for specification
- Energy consumption during operation

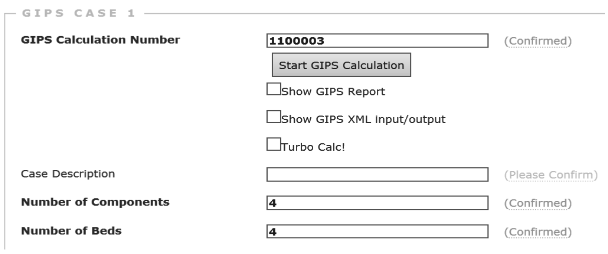

Fig. 4. The integration user interface

3) 5.3.3 Integrations

The configuration system used for this case study is a commercial configurator. For each project much development and integrations are needed according to the stakeholders' requirements. The programmers and developers could perform the plug-ins and integrations according to the stakeholders' request with the desired UI. Figure 4 is the performance of the UI for the integration part. Figure 5 below illustrates an integration example where a specific plug-in makes tables and draws the diagrams according to the tables in the configurator environment.

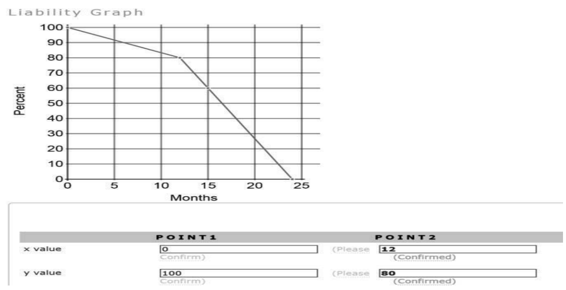

Fig. 5. An example for plug-ins in the configurator environment

J. 5.4 Products and product features

1) 5.4.1 Products

WSA plants include many machines and materials which are all engineer-to-order according to the customer requirements [12]. Most of them are produced inside the company, and some of them are provided by vendors. The company is covering almost seven standard plant types, and these different plants vary in their machines, materials, number of components based on the requested productions. There are more than 20 different components, and some of them are mandatory due to plant type. Depending on the expected product, others can be optionally selected.

2) 5.4.2 Products features

The product features for the case study focus on property models and product structure models as described by Hvam et al. [12]. No cycle models are considered, as the products are not evolving according to customers' needs throughout the phases. The product functions and properties to be modelled are for example the price, volume, size, mechanical and chemical properties built in our property model. The product structure defines how the products are built up and which parts they consist of. The solution principles in our example include the cooling of machines during chemical process.

3) 5.4.3 Input/ output (level of details)

Figure 6 gives us a very brief overview of the information needed for our project. The research work for finding a tool to manage the level of detail for input gathering during the first stages of the project is in process. Currently, reverse engineering for finding the outputs' level of detail is considered. As an example, stakeholders asked for Price Calculation Sheets (PCSs), which are a combination of all component prices according to their internal selections and size, the engineering hours based on the plant complexities, consultancy hours, transportation expenses depending on the size and type, insurance, and destination. Taking these requirements for the PCS, it is possible to search for the relevant inputs.

K. 5.5 Project plan and modelling approaches

1) 5.5.1 Product Variant Master

All the discussions about understanding the structure of each individual component have been performed via

PVM as a common language between domain experts and the configuration team.

2) 5.5.2 Documentation and maintenance

Concerning the complications in the WSA plants and updating importance to the engineers in all fields, the programming of a documentation system was started in the early phases of the project. For a long time the idea was discussed to use XML files from the configurator with descriptions to make it possible to transfer all the information inside the configurator with no unnecessary manual intervention. Furthermore, everything inside the configurator, from attributes to rules, will be visible and understandable for everybody in the company and enable sending comments and updates directly to the responsible.

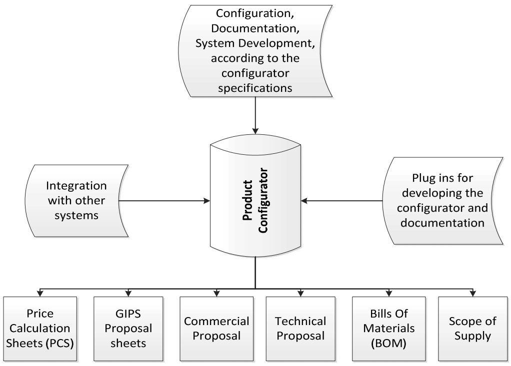

Fig. 6. *The model subject layer and integration with other systems*

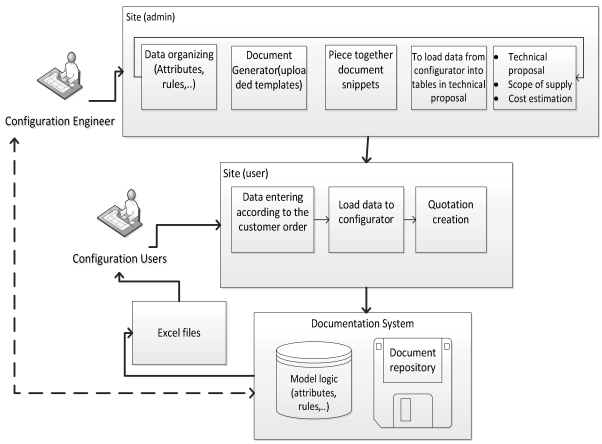

Fig. 7. Documentation and maintenance

3) 5.5.3 Identification of Stockholders and their requirements using use case diagrams

As mentioned, scenarios and flowcharts for the scenarios are a part of the use cases in RUP. In Figure 7 the use case for the mentioned company has been demonstrated. In fact, specific rules for the use case diagrams should be take into consideration, as in RUP use cases are utilized to capture only the functional requirements [5]. Figure 8 shows the specific use case diagram utilized in the project. However, some use cases, such as integration and documentation, are to be explained in separated use cases as separate sub-projects. In this project the general iteration process has been used, as described in the previous section.

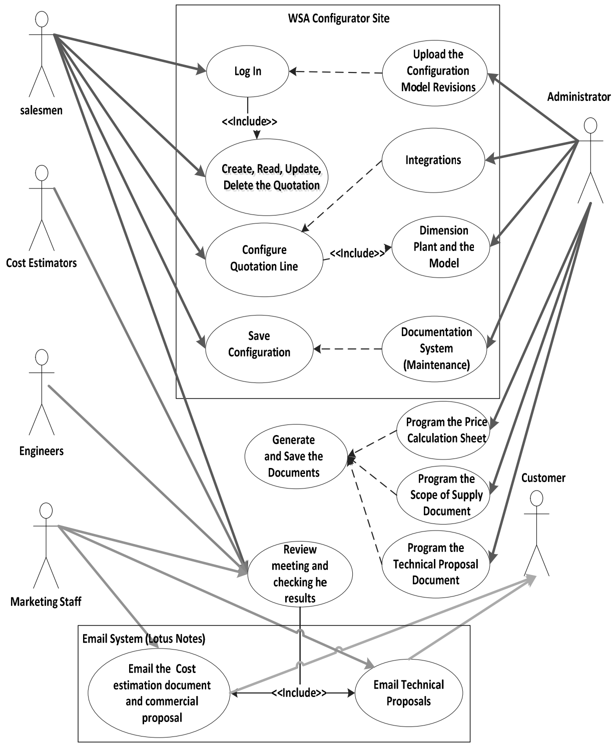

Fig. 8. Use case diagram

4) 5.5.4 Component-based development

The purpose of using a component based structure is to break a big complicated project into smaller pieces, making the process easier both for users and developers. When categorizing the expected results and outputs from the configurator, the expectations for the project become clear. Table 2 depicts the weighted components and determines their priorities and importance in the project. As indicated, the configuration project is expected to be challenging as a number of different complex components with varying priorities have to be implemented.

Table 2. *An example for the components weighting*

Component name	Expected result	Weight (0-10)
Condenser	Scope of Supply	9
	Bills of Material	10
	Technical Proposal	5
	Quotations	5
	Hardware lists	8
	Process simulation for integration…	10
Result		No of Cond.* (∑/No)=~2*8

6. CONCLUSION

This paper clarifies that having a standard framework for implementing configuration projects has a remarkable effect on decision making in the early phases of a project. The experiences from applying and adjusting the Rational Unified Process in this paper reveal a standard way of scoping the configuration systems. The research confirms that having a certain scope for determining the stakeholders' requirement, modelling tools, input and output managing, level of details, maintenance and documentation is vital for the success of configuration projects.

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