UML Based Requirement Management Process in Mobile Multimedia Software Projects

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Tiivistelmä

Vaatimushallinta on tärkeä aliprosessi ohjelmistojen kehityksessä. Sen tarkoituksena on varmistaa, että projektin tuotos vastaa asiakkaan ja muiden sisäisten ja ulkoisten projektiin osallisten sovittuja odotuksia. Ilman toimivaa vaatimushallintaprosessia projektit eivät onnistu pysymään luvatuissa aika, budjetti, laajuus ja laatukehyksissään.

Vaatimuksiin liittyvien haasteiden ratkaisemiseksi tutkittiin viimeaikaisia laajennuksia UML kuvauskieleen. Näitä UML laajennuksia käyttämällä voidaan mallintaa asiakkaan liiketoimintaprosessit ja vaatimukset. Nykyisin UML:ää käytetään laajasti ohjelmistonsuunnittelussa. Mutta kun sitä käytetään myös mallintamaan liiketoimintaprosesesseja ja vaatimuksia siitä seuraa useita parannuksia perinteiseen tapaan hallita vaatimuksia: vaatimusten jäljittäminen toteutukseen on paljon helpompaa, ongelmallisten asioiden ja niiden vaatimusrelaation kommunikointi on tehokkaampaa, järjestelmän kokonaisuuden hahmottaminen on jakautunut laajemmalle projektitiimissä ja toimitettavaa järjestelmää kuvaavasta mallista tulee kattavampi, integroiduimpi ja enemmän todellisuutta vastaava.

Tutkimuksen tuotoksena on uudentyyppinen vaatimushallintaprosessi. Tämä aliprosessi on sulautettavissa ja sovellettavissa mille tahansa ohjelmointikielelle. Se sopii monentyyppisiin ohjelmistonkehitysprosesseihin ja projekteihin. Organisaation täytyy myös hallita UML ja siihen liittyvien työkalujen käyttö.

Asiasanat
UML, SysML, vaatimukset, vaatimushallinta, projektinhallinta, ohjelmistotuotanto, mallinnus

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Abstract

Requirements management is an important sub-process in software development lifecycle. Its purpose is to assure that the project outcome meets the expectations of the customers and other internal or external stakeholders. Without a proper requirement management projects will certainly fail to deliver within the promised time, budget, scope and quality.

To better cope with the requirement related challenges extended Unified Modeling Language (UML) methodologies were studied. These UML extensions can be used to model the business processes and requirements. Currently the UML is extensively used in the industry to design software systems. But when used also to model the business processes and requirements a number of benefits over the tradional way of managing requirements result: tracebility from requirements to design and to implementation is much easier, communication of complex issues and their relation to requirements is much enhanced, understanding of the system behaviour is distributed in the project team and the system model describing the product is more complete, integrated and accurate.

As a result of this thesis new type of requirement management process was created. This process is embeddable and applicable to any implementation language and many types of development processes and projects. To succesfully deploy such a process one has to have the necessary tool support and the organisation must be UML literate.

Keywords
UML, SysML, Requirements, Requirement Management, Project Management, Modeling

Confidentiality
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1 INTRODUCTION

The motivation to study this topic comes from the experiences gained over ten years of professional career on demanding multi-site mobile multimedia software projects in two leading companies of the industry. I have had the opportunity to work in various roles: As a Developer, Tester, Test Manager, Quality Manager, Release Manager, Requirement Analyst, Senior Architect and Project Manager. Based on my experiences I share the opinion of many other professionals in the industry that managing the outcome of software development is always very difficult. There are many methods and processes developed that have improved the way engineers work in project teams. However, I have personally felt that there is a lack of methods and processes to nit the complex requirements into actual practical implementation work. There is all too wide a gap between typical requirement specification and architecture not to mention code and test cases.

In the process of narrowing this information gap, as this thesis will present, that by extending the use of UML as a way to design the software to model business processes, requirements and use the advanced capability to link different diagrams in a sophisticated way, significant improvements are achieved. When this process has been piloted in project teams they have better managed the complexity of building demanding software applications. This has led to improvement in the predictability of the achievable outcome, leading to better products, on time and with increased customer satisfaction.

TABLE OF CONTENTS

2 INTRODUCTION TO SOFTWARE ENGINEERING

"Software engineering is the engineering discipline through which software is developed." [1] Commonly the development of software product involves following activities (i.e. tasks): finding out what the customer needs are, composing this into requirements, designing these into a new or existing architecture, programming (i.e. coding or implementing), testing (i.e. verifying or validating), deploying and maintaining the software. These activities are controlled by means of a software development process, which gives development a structure. There is a multitude of process models to choose from, each describing approaches to a variety of activities that take place during the development process. Used terminology is different between process models. For example, depending on the used software development process, activities are grouped into different phases (i.e. stages or steps) in the lifecycle of a project.

To give an overview on topic of software engineering and remain neutral to used development process, categorization found in the Software Engineering Body of Knowledge (SWEBOK), which is closest of being authorized source of defining what software engineering is, is used. SWEBOK divides software engineering into ten knowledge areas: requirements (management), design, construction (i.e. implementation), testing, maintenance, configuration management, engineering management, engineering process, tools and methods, quality. [2]

2.1 Software Engineering Process

Each organization should adopt the most appropriate development process for their line of business and projects. Each process model has its advantages and disadvantages. Discussion on the subtle and not so subtle differences between the various software development processes is out of the scope of this thesis.

The sub-process defined in this thesis to manage requirements with UML based methods can be embedded to be part of any development process, which gives emphasis on defining requirements. One particular example of iterative development process could be Rational Unified Process (RUP) or any evolution of that model (e.g.

OpenUP, ICONIX) [6]. An example of the approach selected in the RUP is presented in Figure 1.

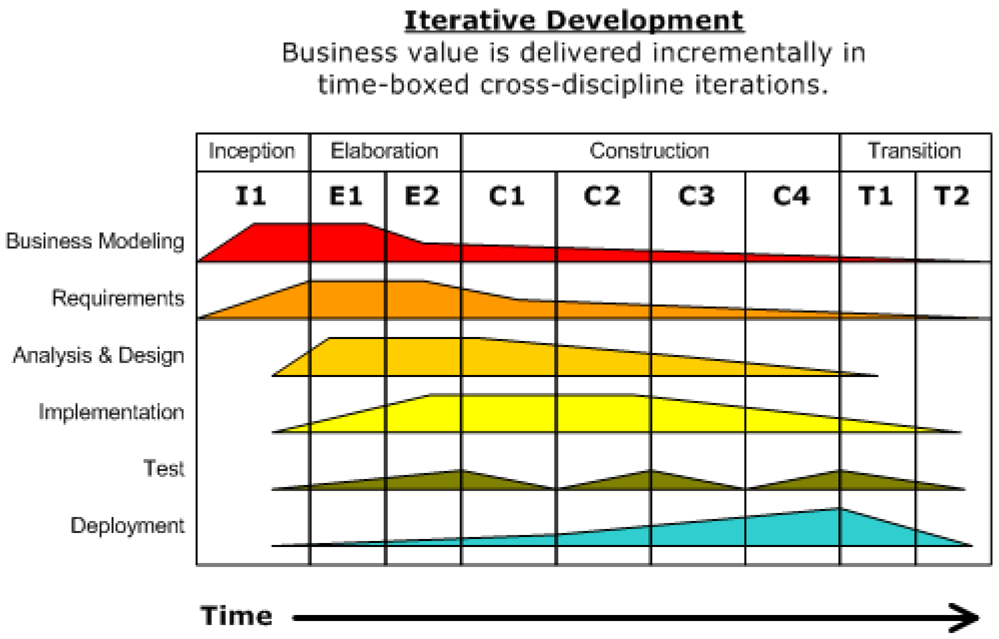


Figure 1: RUP phases and disciplines [6]

As can be seen in Figure 1 the RUP project starts ('Inception' phase) with business modeling and requirements and it is continued with analysis and design activities, followed by implementation, testing, and deployment tasks. Each continuing concurrently and having their natural resource usage peaks in different phases of the project.

2.2 Requirements Management

Requirements management is the process of eliciting (i.e. gathering the requirements from stakeholders), analyzing (i.e. checking for consistency and completeness), documenting (i.e. specifying), and validating (i.e. making sure the specified requirements are correct) requirements and then controlling the change and communicating it to relevant stakeholders. It is a continuous process throughout a project. The purpose of requirements management is to assure the organization meets the expectations of its customers and other internal or external stakeholders. [3], [4]

Proper requirement management is vital for project success. A widely referenced CHAOS study on software project failures revealed that a half (48,1%) of a project's primary causes of failure link directly to requirements management. Top three reasons were 'lack of user input', 'incomplete requirements and specifications' and 'changing requirements and specifications'. Table 1 lists the requirement related reasons out of top ten reasons for project failure revealed by the CHAOS study.

Table 1: Requirement related reasons for project failures [5]

1. Lack of User Input 12.8%
2. Incomplete Requirements & Specifications 12.3%
3. Changing Requirements & Specifications 11.8%
7. Unrealistic Expectations 5.9%
8. Unclear Objectives 5.3%

The primary focus of this thesis is to apply advanced UML methodologies and provide requirement process that aids the organization to overcome these challenging factors. It is dealt extensively in following chapters. A description on one practical approach to model business processes is described in Chapter 4. MODELING BUSINESS PROCESSES. The visual modeling of requirements using the selected technique is described in Chapter 5. MODELING REQUIREMENTS. The advantages of using the requirement model tightly integrated with structural and behavioral aspects of the system model is described in Chapter 6. UML ELEMENTS AND THEIR RELATIONS TO REQUIREMENTS and the advantageous results are expressed in Chapter 7. CONCLUSIONS.

2.3 Design

Design is defined as both "the process of defining the architecture, components, interfaces, and other characteristics of a system or component" and "the result of [that] process." Viewed as a process, software design is the software engineering life cycle activity in which software requirements are analyzed in order to produce a description of the software's internal structure that will serve as the basis for its construction. More precisely, a software design (the result) must describe the software architecture - that is, how software is decomposed and organized into components - and the interfaces between those components. It must also describe the components at a level of detail that enable their construction [2]. All this can be accomplished with UML modeling which is introduced in Chapter 3 INTRODUCTION TO USE OF MODELS IN SOFTWARE ENGINEERING.

Software design plays an important role in developing software: it allows software engineers to produce various models that form a kind of blueprint of the solution to be implemented, analyze and evaluate these models to determine whether or not they will allow us to fulfill the various requirements. Furthermore, it makes it possible to examine and evaluate various alternative solutions and trade-offs. Finally, the resulting models can be used to plan the subsequent development activities, in addition to using them as an input of implementation and testing.

In this thesis the linking of the design model into the requirement model is studied at a detail level in Chapter 6 UML ELEMENTS AND THEIR RELATIONS TO REQUIREMENTS.

2.4 Implementation

The term software implementation refers to the detailed creation of working, meaningful software through a combination of coding (i.e. programming), unit testing, integration testing, and debugging. Detailed boundaries between design, construction, and testing will vary depending on the selected software development process. [2]

The implementation of software can be significantly aided by the system model, some tools allow a code being generated based on the model constructs or vice versa model being generated from the code. Maintaining the synchronization of the system model and the actual implementation in code is an important issue but is out of scope of this thesis.

2.5 Testing

Testing is an activity performed for evaluating product quality, and for improving it, by identifying defects and problems. Software testing consists of the dynamic verification of the behavior of a program on a finite set of test cases, suitably selected from the usually infinite executions domain, against the expected behavior. Software testing is an activity which should influence the whole development and maintenance process and is itself an important part of the actual product construction. Planning for testing starts with the early stages of the requirement process, and test plans and procedures must be systematically and continuously developed, and possibly refined, as the development proceeds. These test planning and designing activities themselves constitute useful input for designers in highlighting potential weaknesses such as design oversights or contradictions, and omissions or ambiguities in the documentation. [2]

A Requirement model thriven project aids testing efforts by providing important linkage of functional requirements to use cases and then further into test cases. Also, non-functional requirements can be linked to test cases thus through this method the test coverage can be shown. This topic is briefly discussed in Chapter 6. UML ELEMENTS AND THEIR RELATIONS TO REQUIREMENTS.

2.6 Maintenance

Successful software development efforts lead to the deployment of a software product, which satisfies user requirements. Accordingly, the software product do change or evolve. Once in operation, defects are uncovered, operating environments change, and new user requirements surface. The maintenance phase of the life cycle begins following a warranty period or a post-implementation support delivery, but maintenance activities should occur much earlier. [2]

The maintenance phase activities are not studied in this thesis. However, when system model accurately represents the state of the system, maintenance will greatly benefit. If new features are implemented they can be added to the model. Even in a case where system under maintenance has not been modelled, doing modeling afterwords either in part or full allows developers save time in the end. [7]

2.7 Configuration Management

Configuration management can defined as "a discipline applying technical and administrative direction and surveillance to: identify and document the functional and physical characteristics of a configuration item, control changes to those characteristics, record and report change processing and implementation status, and verify compliance with specified requirements." [2]

Configuration management of the model, code, test data and other items and the dependencies between them is important activity during the life cycle of project. As noted in the connection with implementation this is excluded on the thesis scope.

2.8 Software Engineering Management

Software Engineering Management can be defined as the application of management activities: planning, coordinating, measuring, monitoring, controlling, and reporting. These are performed to ensure that the development and the maintenance of software is done in a systematic, a disciplined, and a quantified manner.

Finding the manageable scope for the project is significantly dependent on the requirements. Management decisions are greatly aided by the easily understandable and consistent manner in which the model present the system. This allows the decisions makers to improve the quality of direction given to the project team whether it concerns the scope, time, cost or quality of the project. Especially change management benefits from detailed impact analysis made possible by the model.

The manner in which the management activities are performed depends heavily on the development process used to guide the software engineering as discussed earlier in sub-chapter 2.1 Software Engineering Process.

2.9 Methods, Tools, and Quality

Software engineering methods impose structure on the software engineering activity with the goal of making the activity systematic and ultimately more likely to be successful. Methods usually provide a notation and a vocabulary, procedures for performing identifiable tasks, and guidelines for checking both the process and the product. UML methodologies are extensively applied in this thesis.

Software development tools are the computer-based tools that are intended to assist the software life cycle processes. Tools allow repetitive, well-defined actions to be automated, reducing the cognitive load on the software engineer who is then free to concentrate on the creative aspects of the process. Tools are often designed to support particular software engineering methods, reducing any administrative load associated with applying the method manually. Like software engineering methods, they are intended to make software engineering more systematic, and they vary in scope from supporting individual tasks to encompassing the complete life cycle. Model based requirement management process is very dependent on tool support. The extent in which this process can be applied is limited by the features found on selected tool as stated in Chapter 7. CONCLUSIONS.

The quality benefits achieved by applying UML based requirement management process are discussed in Chapter 7. CONCLUSIONS.

3 INTRODUCTION TO USE OF MODELS IN SOFTWARE ENGINEERING

"A model is a simplified representation of certain aspects of the reality, and this simplification makes it easier to analyze the underlying reality and ultimately understand it better" [8].

A visual model plays a similar role in software development as the blueprints and other plans play in the construction industry. The construction of this model can be considered as designing of software intensive systems. When this model is done those responsible for a software development project's success can assure themselves on the following factors: business functionality is complete and correct, end-user needs are met, and program design supports requirements for scalability, robustness, security, extendibility, and other characteristics. This aids project to avoid expensive and difficult changes in the implementation phase. Other included benefits are:

• Shared understanding of system requirements and design
– Validation of requirements
– Common basis for analysis and design
– Facilitates identification of risks
• Assists in managing complex system development
– Separation of concerns via multiple views of integrated model
– Supports traceability through hierarchical system models
– Facilitates impact analysis of requirements and design changes
– Supports incremental development & evolutionary acquisition
• Improved design quality
– Reduced errors and ambiguity
– More complete representation
• Supports early and on-going verification & validation to reduce risk
• Enhances knowledge capture
[9]

There are number of different modeling languages available, none of them being ideal for every domain and project. The Unified Modeling Language is the most accepted modeling language in the software industry and ISO standard. However, for complex systems it's modeling capabilities are insufficient [10]. To address these shortcomings extension to UML Systems Modeling Language (SysML) was created. In this thesis SysML and particularly it's requirement and callout diagrams to extend the capabilities of model are studied in Chapter 6. UML ELEMENTS AND THEIR RELATIONS TO REQUIREMENTS. Another important aspect of defining software that meets the customer expectations is business process modeling. To have this aspect included in model another UML extension Eriksson-Penker Business Modeling Profile is applied, this is discussed in detail in Chapter 4 MODELING BUSINESS PROCESSES.

3.1 Introduction to Unified Modeling Language

The Unified Modeling Language (UML) is a family of graphical notations, which provides system architects, software engineers, and other team members tools for analysis, design, and implementation of software based systems as well as for modeling business and similar processes. The UML helps engineers to specify, visualize, and document models of software systems, including their structure and design, in a way that meets all of these requirements.

The initial version of UML originated with three leading object-oriented methods (Booch, OMT, and OOSE), and incorporated a number of best practices from modeling language design, object-oriented programming, and architectural description languages. Future revisions of UML have enhanced standard with significantly more precise definitions of its abstract syntax rules and semantics, a more modular language structure, and a greatly improved capability for modeling large-scale systems. [11]

In UML 2.0 it is possible to zoom out from a detailed view of an application to the environment where it executes, visualizing connections to other applications. Alternatively, it is possible to focus on different aspects of the application, such as the

Figure 2: UML 2.2 Diagram types

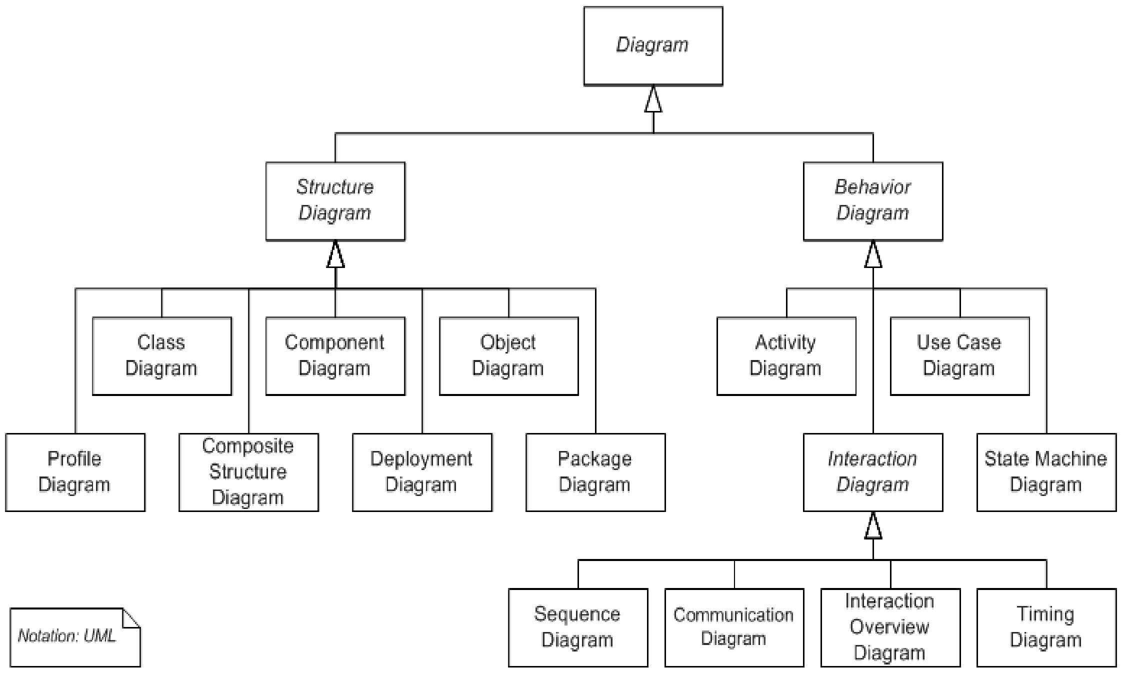
business process that it automates, or a business rules view. The new ability to nest model elements supports this concept directly. [12]

Modeling almost about any type of application, running on any type and combination of hardware, operating system, programming language, and network, is possible with UML. It is built upon fundamental object orientation concepts including class and operation, making it designed for object-oriented languages and environments but it can also be used to model non- object oriented applications.

3.1.1 UML Diagrams

It is very important to distinguish between the UML model and the set of diagrams of a system. A diagram is a partial graphical representation of a system's model. UML diagrams represent two different views of a system model: Static (or structural) and Dynamic (or behavioral). The static view emphasizes the static structure of the system using objects, attributes, operations and relationships. The dynamic (or behavioral) view emphasizes the dynamic behavior of the system by showing collaborations among objects and changes in the internal states of objects.

UML 2.2 has 14 types of diagrams divided into these two categories. Seven diagram types represent structural information, and the other seven represent general types of behavior, including four that represent different aspects of interactions. These diagrams can be categorized hierarchically as shown in Figure 2. [13]



3.1.2 UML Extensions by Profiles

UML profiles provide generic extension mechanism for customizing UML for particular domains and platforms. [14] As previously mentioned, in this thesis two extensions are used: SysML and Eriksson-Penker Business Modeling Profile.

3.2 Introduction to SysML Language

The SysML (Systems Modeling Language) is a general-purpose modeling language for systems engineering applications that is defined as a profile of UML 2. It supports the specification, analysis, design, verification and validation of a broad range of systems and systems-of-systems. These systems may include hardware, software, information, processes, personnel, and facilities. [15]

In particular, the language provides graphical representations with a semantic foundation for modeling system requirements, behavior, structure, and parametrics. SysML represents a subset of UML 2 with extensions needed to satisfy the requirements of the UML for Systems Engineering as indicated in Figure 3. [16]

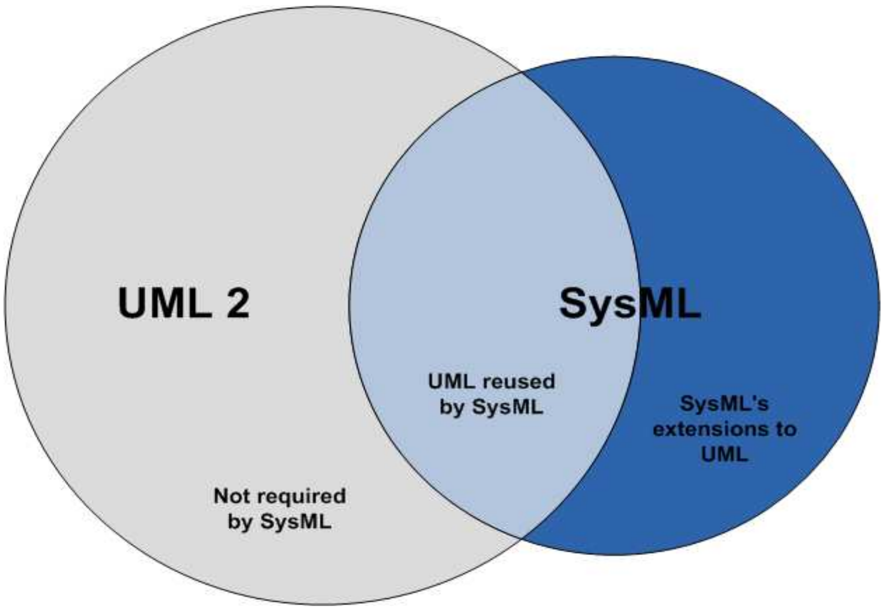


Figure 3: Relationships between SysML and UML

UML captures well the software aspects of the system. However, from the system point of view also non-software components (e.g., hardware, information, processes, personnel, and facilities) need to considered. UML cannot satisfy this need because of its software focus only. SysML extends UML's semantics to model requirements and parametric constraints, though only the requirement modeling of SysML is discussed in this thesis.

3.2.1 SysML's Extensions and Omissions to UML

The most important change is that UML classes are called blocks in SysML, and the class diagram is block definition diagram. The UML composite diagram is called an internal block diagram in SysML [10]. Seven UML 2 diagrams are inherited from UML and two new diagrams are introduced, these changes are illustrated in Figure 4.

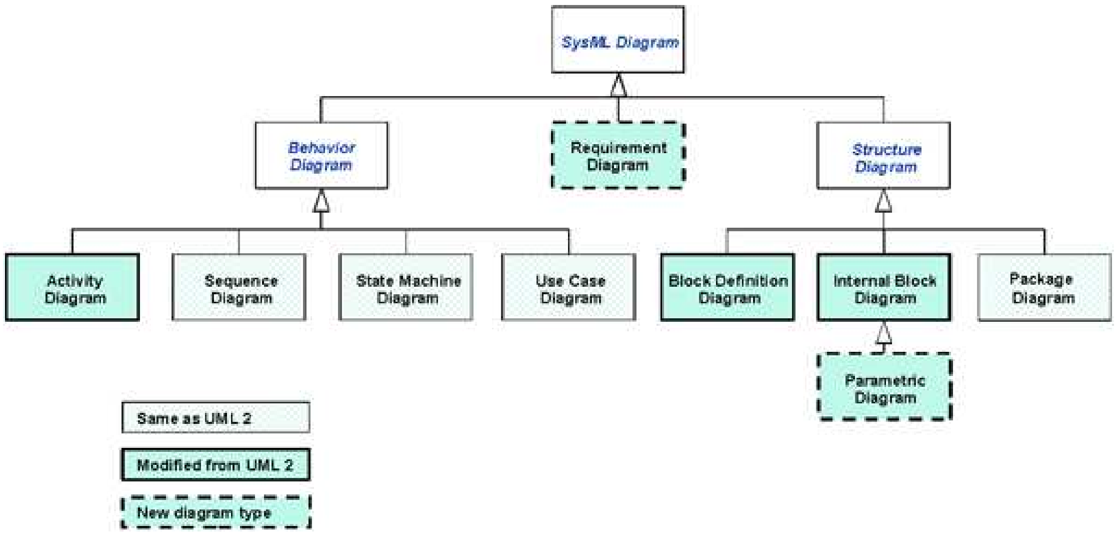


Figure 4: SysML Diagram Types

SysML allocation tables support common kinds of allocations. Whereas UML provides only limited support for tabular notations, SysML furnishes flexible allocation tables that will support requirements allocation, functional allocation, and structural allocation. This capability facilitates automated verification and validation and gap analysis. This is discussed in detail in Chapter 6 UML ELEMENTS AND THEIR RELATIONS TO REQUIREMENTS. With SysML it is possible to use requirement diagrams to efficiently capture functional, performance and interface requirements. If UML is solely used team is subject to the limitations of the Use Case diagrams to define high-level functional requirements.

4 MODELING BUSINESS PROCESSES

4.1 Introduction

"Business processes are the activities that a commercial organisation performs in order to carry out its business. All organisations depend for their competitiveness on the efficiency with which their business processes operate" [17].

For any software project to achieve a commercial success over the bare technical code complete, the solution provider must have a sufficient understanding about customer's business processes. Unfortunately, this step is very often neglected and as a result the software solutions are ill adjusted to support the customer's business, and instead of being enablers in the business they tend to disable opportunities for a organisation. This occurs because from the software provider side there is reluctance to study, so called domain knowledge area of customer, and from customer side there is often lack of interest to understand the software solutions [18]. Therefore, in order to narrow this information gap and integrate the project's stakeholder's vision of the expected outcome, modeling business processes is useful step before requirements engineering.

The extent of a needed research depends generally on the nature of the project: type, size, complexity, criticality, and customer requirements and the chosen development process of the software provider. For example ERP (Enterprise Resource Planning) projects require intimate understanding of the customer's business [19]. In turn smaller and simpler projects the time and energy spent analyzing customer's business process can be minute [20]. Furthermore, good analyst understands that business process model has a broader and more inclusive range than any software system being considered. As a result, an effective business model allows clearly map the scope of the proposed system as well as pieces of the process that must be implemented in other ways, such as manual processes that the software system can not handle [21].

A business process model specification typically consist of the following elements:

• Goal of the process

• Specific inputs and outputs

• Used resources

• Events that drive or affect the process

• Activities and the order in which they are performed

Inputs and outputs often refer to data, but they can also be something that is processed or worked upon. For example, a system requires data input and typically outputs data in return: a report, a completed customer order, etc. Resources can be persons or parts of a system that are involved in performing the activities. Events can be any number of things, which trigger something that initiates a business process. For example a deadline might trigger the start of an invoicing process. [22]

4.2 Selection of Modeling Language

When documenting the process it is very important to keep in mind that a business process model must be in the type of a format that all stakeholders can understand it. There exist a variety of ways to document business processes ranging from textual descriptions to sophisticated models [21]. Four common uses of modeling languages in business processes context are briefly introduced here: UML Use Cases, UML Activity Diagram, Business Process Modeling Notation (BPMN), and UML Extension Eriksson-Penker Business Modeling Profile (EPBE).

Firstly, project utilizing Rational Unified Software Development Process (RUP) or its variants, which gives emphasis to use cases, would model processes through user interactions alone. This can be sufficient way to describe them in many cases [21].

Secondly, the UML activity diagram can be applied to business process modeling. As it states in the UML standard "Activities may be applied to organizational modeling for business process engineering and workflow" [23]. But as brought out by a study by Eloranta, Kallio, Terho (2006), the use of an activity diagram requires the modeler to carefully select, which elements are appropriate for business modeling and it will require the audience to be literate on the UML activity diagram notation [24].

Thirdly, Business Process Modeling Notation is widely used among the business people and being designed for this sole purpose can indeed model the processes accurately. It has it similarities to UML activity diagram but at least while writing this these to modeling languages have not converged even though there is growing pressure to align these two modeling languages [25].

Fourthly, the model that is utilized in this thesis is a business processing model extension from UML, the Eriksson-Penker Business Extensions also used in some extent in software projects [24]. It presentation is easy-to-understand and other UML models can be conveniently linked to it in the used CASE tool [22]. In Figure 5 is illustrated a generic structure of process model diagram using selected notation and in Figure 6 there is an example how this is utilized to model the process of creating business process models.

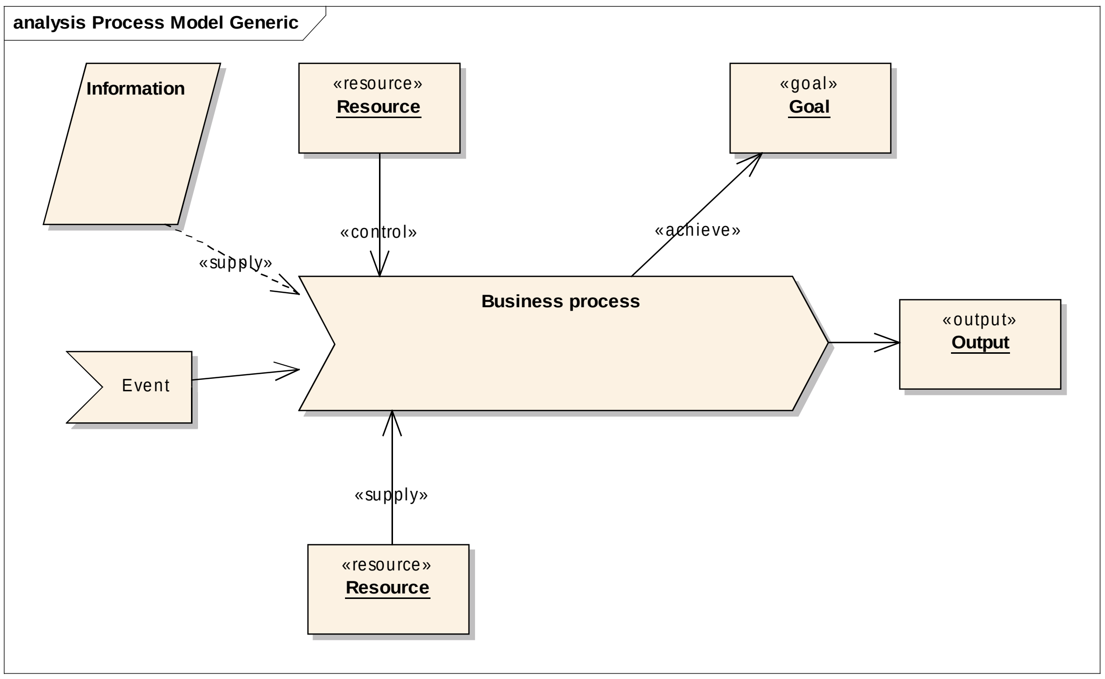


Figure 5: Illustration of a generic structure of process model diagram

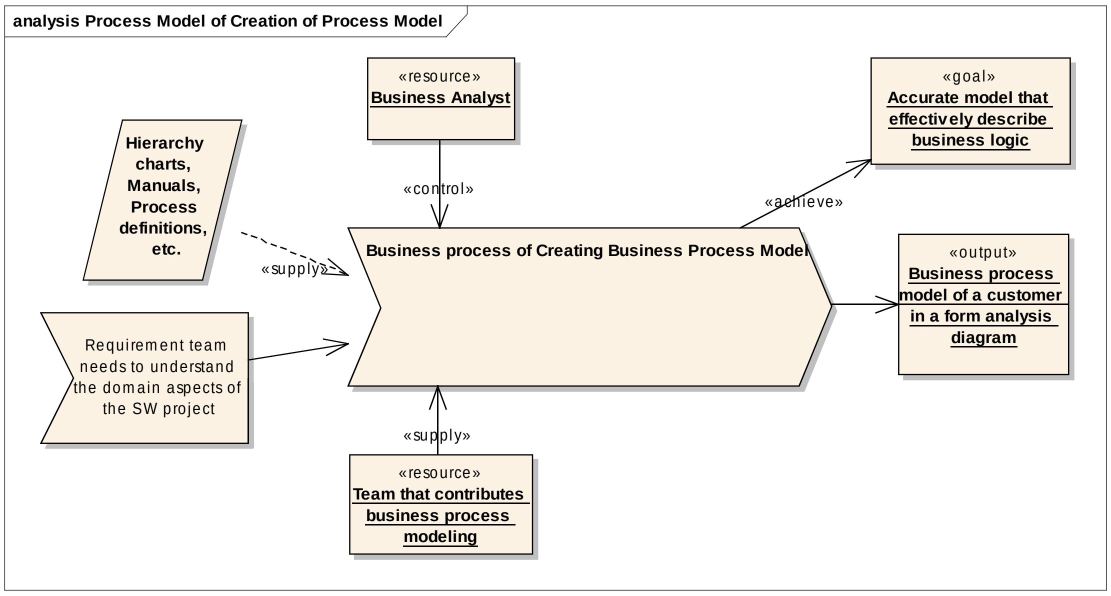

analysis Process Model of Creation of Process Model
«resource»
Business Analyst
«goal»
Accurate model that effectively describe business logic
Hierarchy charts, Manuals, Process definitions, etc.
«control»
«achieve»
Business process of Creating Business Process Model
«output»
Business process model of a customer in a form analysis diagram
«supply»
Requirement team needs to understand the domain aspects of the SW project
«supply»
«resource»
Team that contributes business process modeling

Figure 6: Example showing how an analysis diagram is used to describe a process related to creating a model of business processes.

Figure 6 shows how the triggering event for the process is the need to understand the domain aspects of the software project better. The principal stakeholder is a person who acts as a Business Analyst who facilitates the process by taking the information input (hierarchy charts, manuals, existing process definitions, etc.) and using the other resources that contribute the process model creation (a team may consist of department heads, experts, project leads, etc.). The goal is to accurately model the business as it is or how the team wants it to be when the system is ready. This goal is achieved by creating a business model diagram that contains relevant information.

5 MODELING REQUIREMENTS

5.1 Definition of Requirement

In engineering, a requirement is a singular documented need of what a particular product or service should be or do. It is most commonly used in a formal sense in systems engineering or software engineering. It is a statement that identifies a necessary attribute, capability, characteristic, or quality of a system in order for it to have value and utility to a user. Table 2 defines characteristics of well-defined requirement. [27]

Table 2: Characteristics of well-defined requirement

Characteristic	Explanation
Cohesive	The requirement addresses one and only one thing.
Complete	The requirement is fully stated in one place with no missing information.
Consistent	The requirement does not contradict any other requirement and is fully consistent with all authoritative external documentation.
Correct	The requirement meets all or part of a business need as authoritatively stated by stakeholders.
Current	The requirement has not been made obsolete by the passage of time.
Externally Observable	The requirement specifies a characteristic of the product that is externally observable or experienced by the user. "Requirements" that specify internal architecture, design, implementation, or testing decisions are properly constraints, and should be clearly articulated in the Constraints section of the Requirements document.
Feasible	The requirement can be implemented within the constraints of the project.
Unambiguous	The requirement is concisely stated without recourse to technical jargon, acronyms (unless defined elsewhere in the Requirements document), or other esoteric verbiage. It expresses objective facts, not subjective opinions. It is subject to one and only one interpretation. Vague subjects, adjectives, prepositions, verbs and subjective phrases are avoided. Negative statements and compound statements are prohibited.
Mandatory	The requirement represents a stakeholder-defined characteristic the absence of which will result in a deficiency that cannot be ameliorated.
Verifiable	The implementation of the requirement can be determined through one of four possible methods: inspection, analysis, demonstration, or test.

In the classical engineering approach, sets of requirements are used as inputs into the design stages of product development. When requirements are described manner outlined in Table 2 they effectively show what elements and functions are necessary for the particular project. [27]

In SysML standard [28] requirements are defined trough Requirement Diagram. A requirement is defined as a stereotype of UML Class. The «requirement» stereotype represents a text based requirement it includes id and text properties. Figure 7 illustrates this. It can be extended with user defined properties e.g. verification method and user defined requirements categories (e.g. functional, interface, performance).

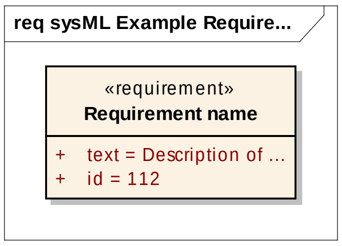


Figure 7: Simple example of SysML requirement diagram with one requirement

5.2 Requirements Relationships and Rationale

Several requirements relationships can be specified via stereotyped dependencies in UML that enable the modeler to relate the requirements to other requirements as well as to other model elements. The «deriveReqt» and «satisfy» dependencies describe the derivation of requirements from other requirements and the satisfaction of requirements by design, respectively. The «verify» dependency shows the link from a test case to the requirement or requirements it verifies. In addition, the UML «refine» dependency is used to indicate that an SysML model element is a refinement of a textual requirement, and «a copy» relationship is used to show reuse of a requirement within a different requirement hierarchy. [29]

The «rationale» concept can be used to annotate any model element to identify supporting rationale including analysis and trade studies for a derived requirement, a design or some other decision. A rationale is a SysML model element that can be associated with either a requirement or a relationship between requirements. As the name implies, the rationale is intended to capture the reason for a particular design decision. Although rationale is described here for requirements, it is a model element that can be applied throughout the model to capture the reason for any type of decision. [28] Example of its usage can be seen in Figure 8.

A composite requirement can contain sub-requirements in terms of a requirements hierarchy, specified using the UML namespace containment mechanism. This relationship enables a complex requirement to be decomposed into its containing child requirements. A composite requirement may state that the system shall do A and B and C, which can be decomposed into the child requirements that the system shall do A, the system shall do B, and the system shall do C. An entire specification can be decomposed into children requirements, which can be further decomposed into their children to define the requirements hierarchy. These relations ships are illustrated in Figure 8.

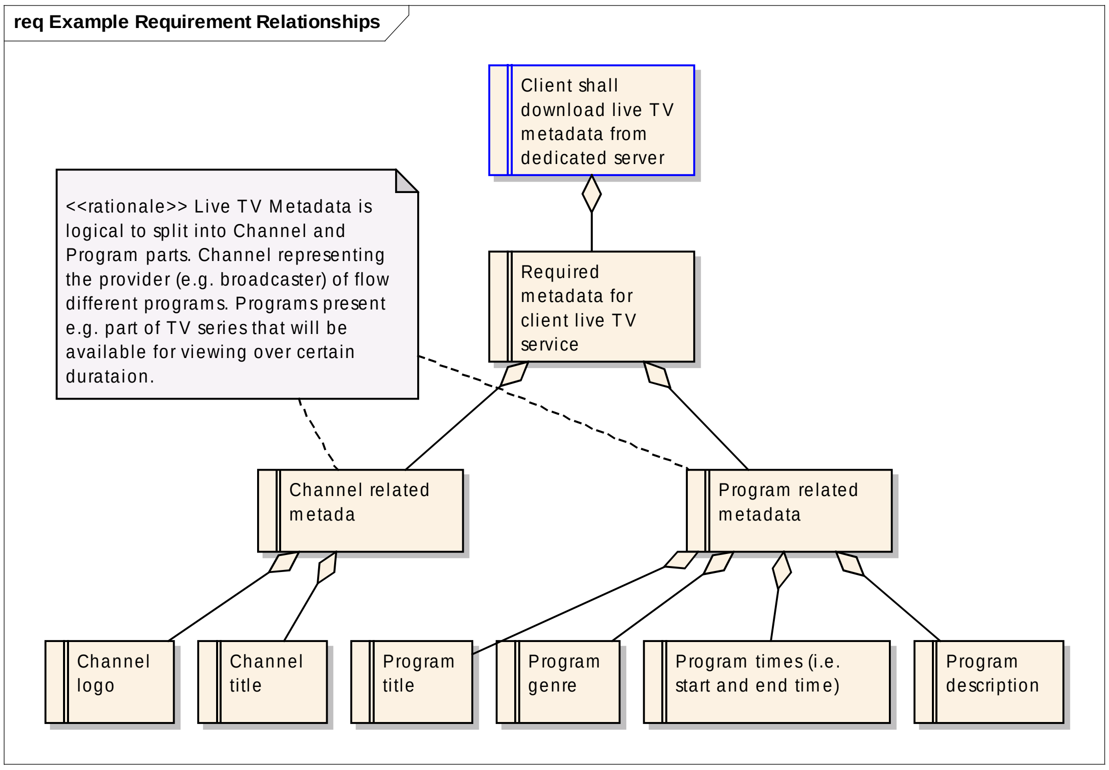

req Example Requirement Relationships
Client shall download live TV metadata from dedicated server
<<rationale>> Live TV Metadata is logical to split into Channel and Program parts. Channel representing the provider (e.g. broadcaster) of flow different programs. Programs present e.g. part of TV series that will be available for viewing over certain durataion.
Required metadata for client live TV service
Channel related metada
Program related metadata
Channel logo
Channel title
Program title
Program genre
Program times (i.e. start and end time)
Program description

Figure 8: Composition of Live TV EPG client requirements and use of Rationale

The *“derive requirement”* relationship relates a derived requirement to its source requirement. This typically involves an analysis to determine the multiple derived requirements that support a source requirement. The derived requirements generally correspond to requirements at the next level of the system hierarchy.

The *satisfy* relationship describes how a design or implementation model satisfies one or more requirements. A system modeler specifies the system design elements that are intended to satisfy the requirement.

The *verify* relationship defines how a test case or other model element verifies a requirement. In SysML, a test case or other named element can be used as a general mechanism to represent any of the standard verification methods for inspection, analysis, demonstration, or test. Additional subclasses can be defined by the user if required to represent the different verification methods. A verdict property of a test case can be used to represent the verification result. The SysML test case is defined consistent with the UML testing profile to facilitate integration between the two profiles.

The *refine* requirement relationship can be used to describe how a model element or a set of elements can be used to further refine a requirement. For example, a use case or activity diagram may be used to refine a text-based functional requirement. Alternatively, it may be used to show how a text-based requirement refines a model element. In this case, some elaborated text could be used to refine a less fine-grained model element.

A generic *trace* requirement relationship provides a general-purpose relationship between a requirement and any other model element. The semantics of trace include no real constraints and therefore are quite weak. As a result, it is recommended that the trace relationship not be used in conjunction with the other requirements relationships described above.

6 UML ELEMENTS AND THEIR RELATIONS TO REQUIREMENTS

After modeling business processes, use cases and requirements are usually concurrently modeled. After this developers need to extend the design with diagrams describing the structure of system i.e. architecture and other design aspects such as the dynamics using e.g. sequence diagrams.

6.1 Use Cases

Use case diagrams are useful for requirements management when kept in mind that they are good for capturing interaction between external user and the system. However, there are not enough to describe exhaustively the non-functional characteristic of the system.

The core of a use case description is about answering to a simple questions: *who, what, when* and *how*, and being able to communicate this to the relevant stakeholders. The *who* refers to one or more actors that interact with the system. The *what* describes the actor's goal. The *when* refers to the pre- and post-requisites. When it can be started and when it's completed. Finally, the *how* describes the scenario of events that are needed to accomplish the goal. Figure 9 describes an example use case where 'Mobile TV application downloads EPG information on it's start-up'.

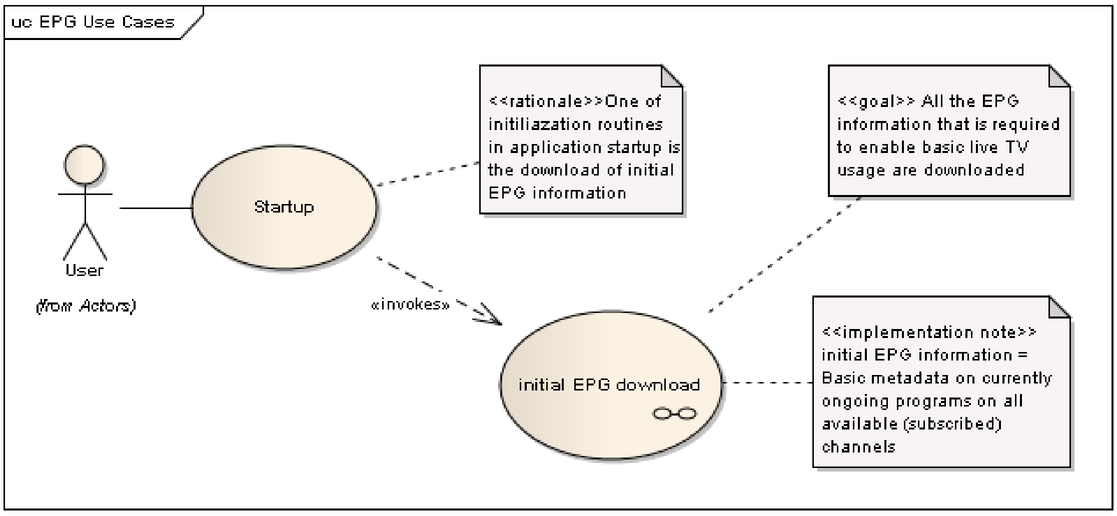

uc EPG Use Cases
<<rationale>>One of initiliazation routines in application startup is the download of initial EPG information
<<goal>> All the EPG information that is required to enable basic live TV usage are downloaded
Startup
User
(from Actors)
«invokes»
initial EPG download
<<implementation note>> initial EPG information = Basic metadata on currently ongoing programs on all available (subscribed) channels

Figure 9: Use case diagram describing intial download of EPG information

As can be seen in Figure 9 it is the user who starts the application which then triggers the initial EPG download use case. Download of ongoing live TV show's metadata information is accomplished (for reference see also Figure 8. Composition of Live TV EPG client requirements and use of Rationale). Case is executed at the application startup and it is completed when necessary EPG information has been downloaded. To further define how this accompished, the expression power of use case can be extended with a nested diagram such as sequence diagram.

6.2 Sequence Diagrams

A sequence diagram is an interaction diagram that shows how processes or objects operate with one another and in what order. In parallel are vertical lines (lifelines), they are different processes or objects that live simultaneously, and, as horizontal arrows, the messages exchanged between them, in the order in which they occur. This allows the specification of simple runtime scenarios in a graphical manner. Figure 10 is a nested sequence diagram that describes the interaction needed to download initial EPG information. It describes how application components: main, user interface, storage, EPG client communicate with EPG server to accomplish this goal.

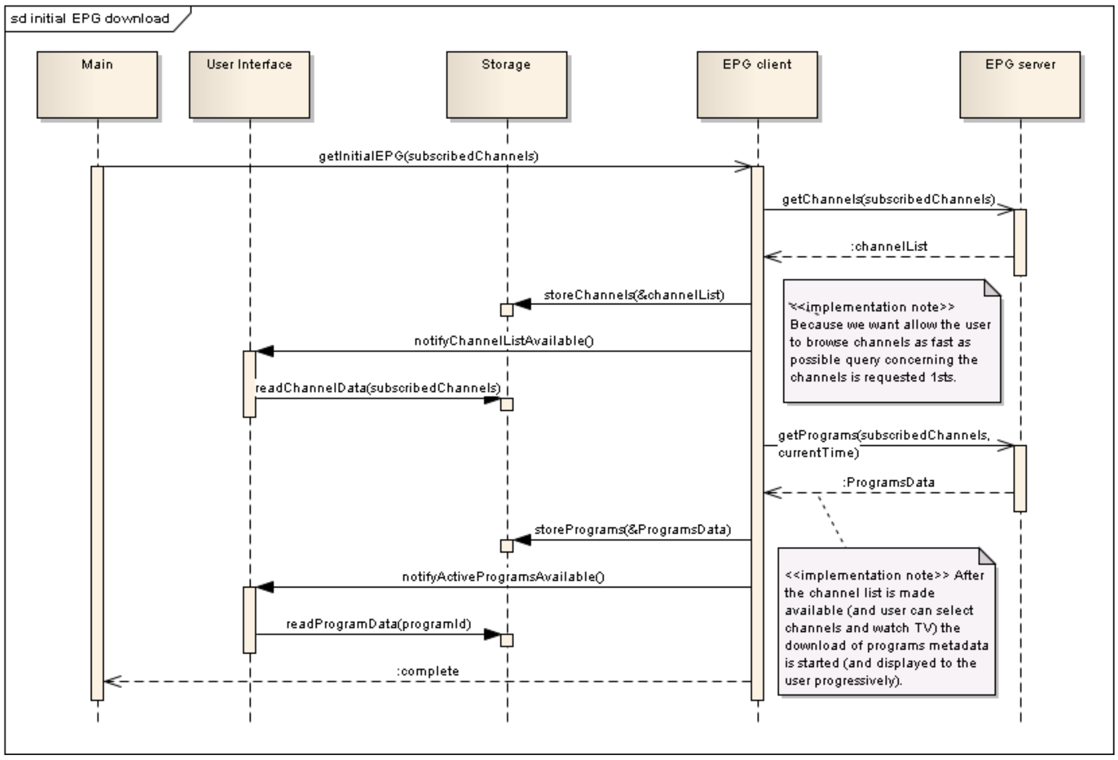

sd initial EPG download
Main
User Interface
Storage
EPG client
EPG server
getInitialEPG(subscribedChannels)
getChannels(subscribedChannels)
:channelList
storeChannels(&channelList)
<<implementation note>> Because we want allow the user to browse channels as fast as possible query concerning the channels is requested 1sts.
notifyChannelListAvailable()
readChannelData(subscribedChannels)
getPrograms(subscribedChannels, currentTime)
:ProgramsData
storePrograms(&ProgramsData)
notifyActiveProgramsAvailable()
<<implementation note>> After the channel list is made available (and user can select channels and watch TV) the download of programs metadata is started (and displayed to the user progressively).
readProgramData(programId)
:complete

Figure 10: Sequence diagram (nested element of use case) defining details of initial EPG download

6.3 Allocations and Callout diagram

Allocation is the term used by systems engineers to denote the organized cross-association (mapping) of elements within the various structures or hierarchies of a user model. The concept of "allocation" requires flexibility suitable for the abstract system specification, rather than a particular constrained method of a system or a software design. System modelers often associate various elements in a user model in abstract, preliminary, and sometimes tentative ways. Allocations can be used early in the design as a precursor to more detailed rigorous specifications and implementations. The allocation relationship can provide an effective means for navigating the model by establishing cross relationships, and ensuring the various parts of the model are properly integrated. The callout notation is used when requirements do not appear on other kinds of diagrams, or when other model elements do not appear on a requirement diagram [28]. Figure 11 presents an example of this where in the use case presented earlier is associated with the requirements that it realizes.

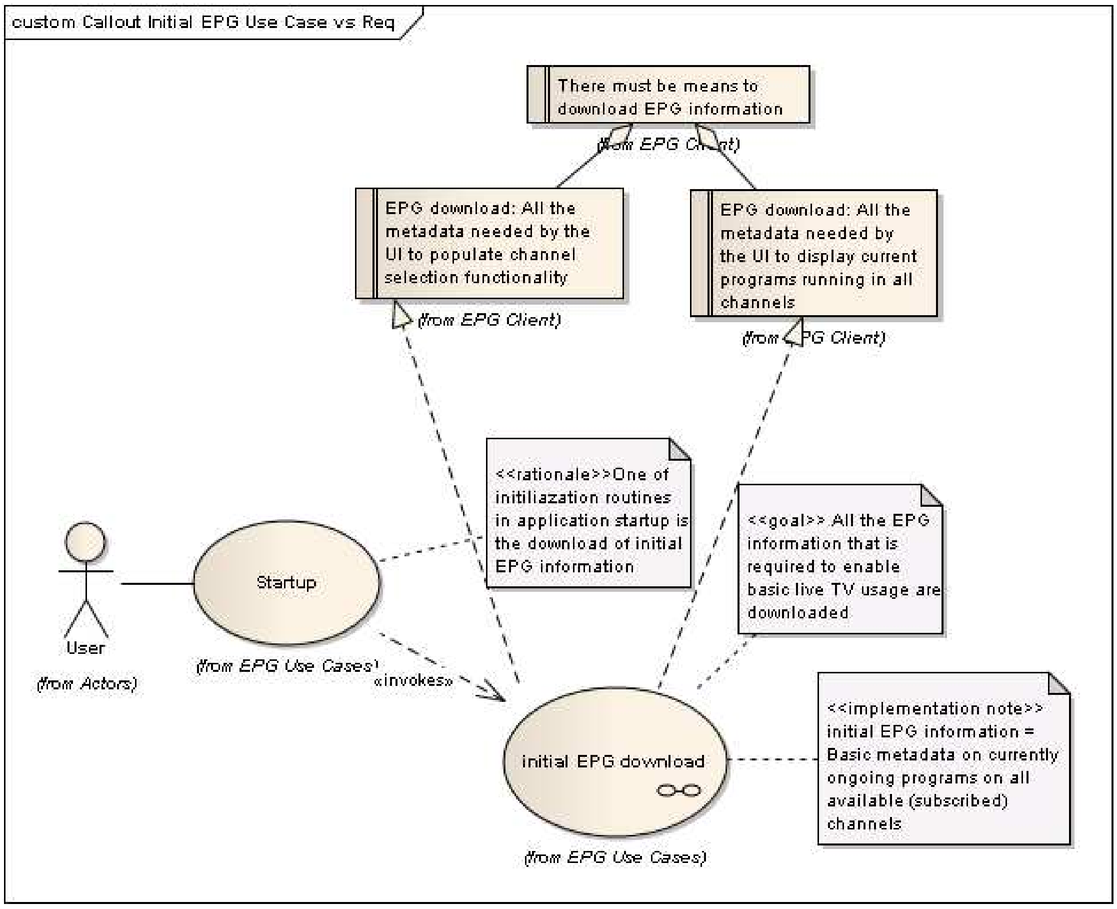

custom Callout Initial EPG Use Case vs Req
There must be means to download EPG information
(from EPG Client)
EPG download: All the metadata needed by the UI to populate channel selection functionality
(from EPG Client)
EPG download: All the metadata needed by the UI to display current programs running in all channels
(from EPG Client)
<<rationale>>One of initiliazation routines in application startup is the download of initial EPG information
<<goal>> All the EPG information that is required to enable basic live TV usage are downloaded
User
(from Actors)
Startup
(from EPG Use Cases)
«invokes»
initial EPG download
(from EPG Use Cases)
<<implementation note>> initial EPG information = Basic metadata on currently ongoing programs on all available (subscribed) channels

Figure 11: Callout diagram describing how 'initial EPG download' use case implements the two sub-requirements of EPG download

7 CONCLUSIONS

7.1 UML Based Requirement Management Process

A typical requirement management process consists of several sub-processes: elicitation, analysis, documentation (i.e. specification), validation, and change control. This is valid also for the UML-RM process with the exception that documentation is not really a separate activity, since in this UML-RM process the model is created from beginning and updated constantly.

A requirement analyst is the main responsible for documentation efforts and the principal owner of the requirement model [31]. Therefore, typically the analyst would be the person that implements business process, use case, and requirement diagrams. However, all users of the system model are applying, extending, and connecting to these diagrams and their elements. Connecting the requirement model to a design model is an essential to provide added value on understanding the problem to be solved. The model that is one of the project outcomes owned by whole project team.

7.1.1 Elicitation

Gathering the requirements from stakeholders is one of the first activities that happen in R&D projects. Figure 12 presents such a sub-process where the requirement analyst together with the requirement team compiles an initial requirement in place. Typically this would happen in a manner where the analyst would meet the customer in a (series) of meetings where new product features or use cases would be discussed. [31]

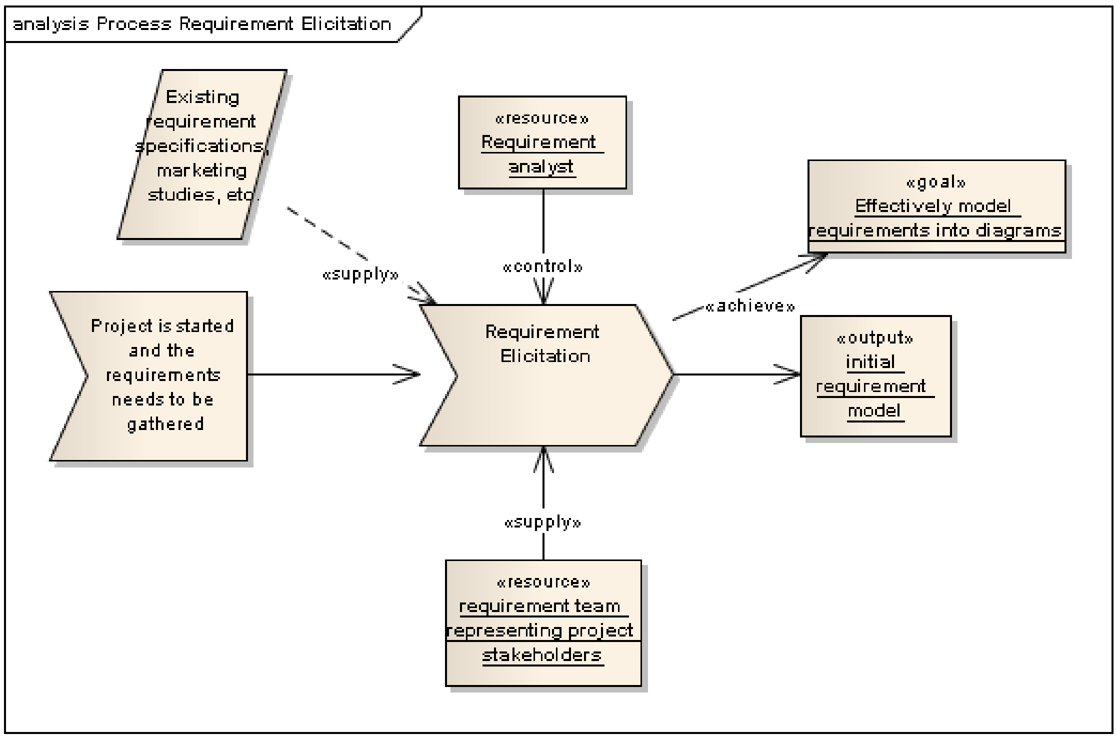

analysis Process Requirement Elicitation
Existing requirement specifications, marketing studies, etc.
«resource» Requirement analyst
«goal» Effectively model requirements into diagrams
«supply»
«control»
Project is started and the requirements needs to be gathered
Requirement Elicitation
«achieve»
«output» initial requirement model
«supply»
«resource» requirement team representing project stakeholders

Figure 12: Requirement elicitation process diagram

An existing product's requirement specifications, market studies, customer requests can help the analyst to determine what are the initial requirements for a software product. A good analyst acts pro-actively to help the users to articulate the system capabilities they need to meet their business objectives. Users naturally emphasize the system’s functional requirements, but discussion is needed to include quality attributes, performance goals, business rules, external interfaces and constraints. A well done elicitation can significantly reduce the need for costly change requests later in the project.

An organization must select how many times the elicitation sub-process happens in the lifetime of the project: only once in the beginning of the project or at the start of each iteration of development. If the development process is similar to the waterfall model then it would be natural to try to describe all the requirements in one-time effort and handle possible changes through a change control process. On the other hand, if the selected process has relatively short iterations, then elicitation would be happening in the beginning of each iteration.

Depending on the project complexity an output contains a varying number of business processes, use case and requirement diagrams.

7.1.2 Analysis

When elicitation is completed requirements need to be checked for completeness and consistency. This sub-process is effectively a review process where the team inspects the requirement model. Experts from development, testing and other functional areas of project are involved in auditing and approving the requirement set.

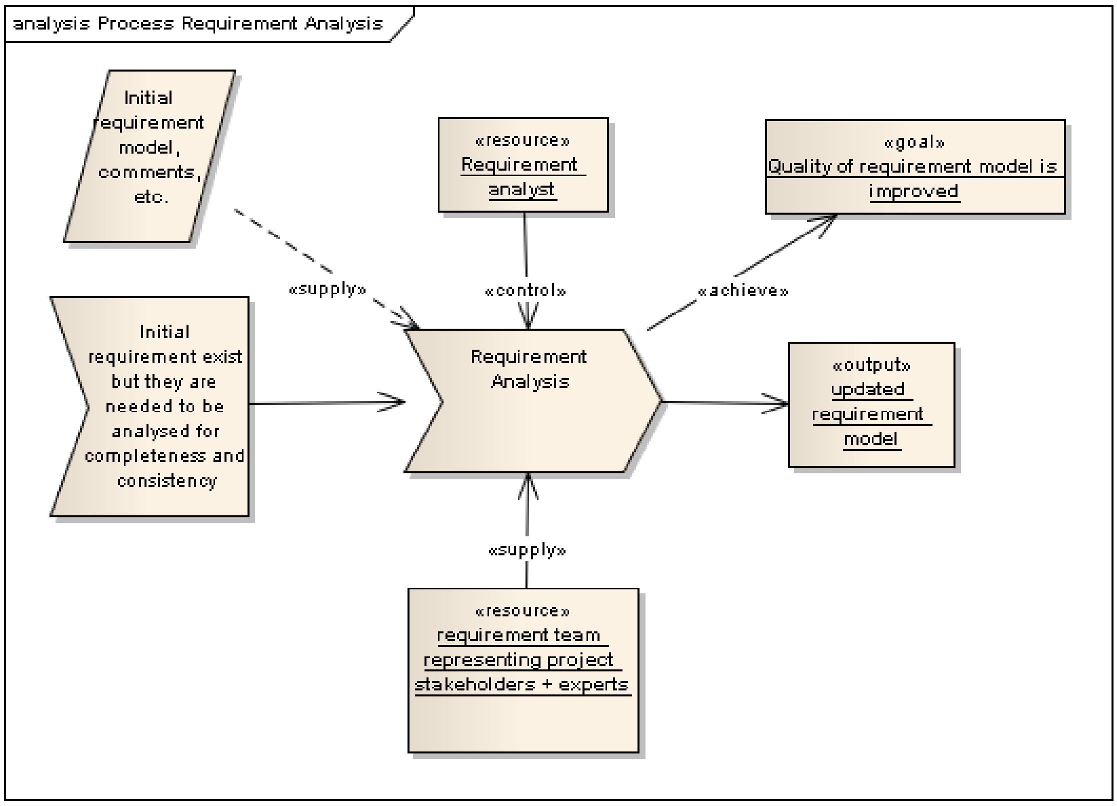

analysis Process Requirement Analysis
Initial requirement model, comments, etc.
«resource» Requirement analyst
«goal» Quality of requirement model is improved
«supply»
«control»
«achieve»
Initial requirement exist but they are needed to be analysed for completeness and consistency
Requirement Analysis
«output» updated requirement model
«supply»
«resource» requirement team representing project stakeholders + experts

Figure 13: Requirement analysis process diagram

In practice, this could be a scheduled meeting with given material (initial requirement model) and time to give review comments that are discussed in the review meeting where analyst could act as a chairperson and a secretary.

Review participants should look for derived requirements that are a logical consequence of the customers requests, as well as hunting for those implicit requirements that they expect but haven’t verbalized. Attention should be placed on vague, weak words that cause ambiguity and confusion. Auditors should point out conflicting requirements and areas that need more detail. Functional requirements should be described in a suitable level of detail for the developers.

After one or more review meetings and approval from the customer and project management the requirement model should be stable enough to be 'frozen' i.e. all the new requirements or changes to existing ones are implemented under change control process.

7.1.3 Validation

Analysis and validation sub-processes aim for the same goal: Ensuring that the documented requirements satisfy the customer needs and that they are clear, complete, correct, feasible, necessary, traceable, unambiguous, and verifiable. The subtle distinction of the two sub-processes is in the time line of the activity. An analysis needs to happen after elicitation without the existing design diagrams, code and test cases. Whereas validation happens when the design model, implementation and test model are at least partially ready. Figure 14 describes such a process.

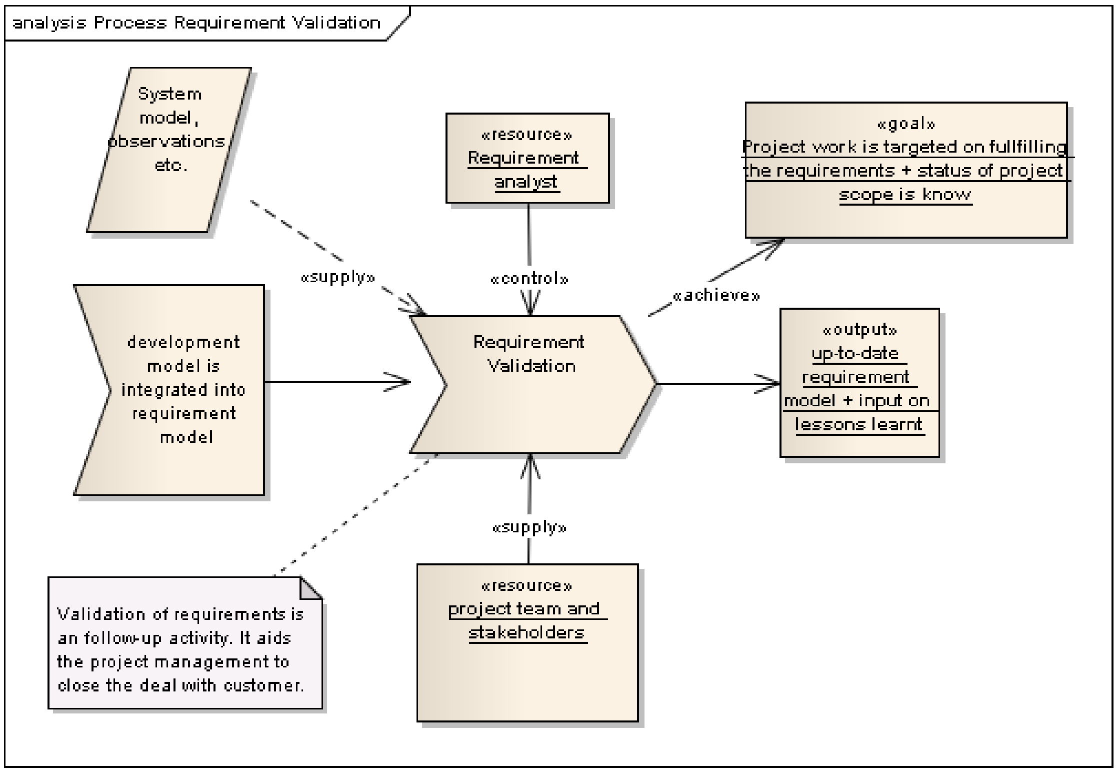

analysis Process Requirement Validation
System model, observations etc.
«supply»
«resource» Requirement analyst
«control»
«goal» Project work is targeted on fullfilling the requirements + status of project scope is know
«achieve»
development model is integrated into requirement model
Requirement Validation
«output» up-to-date requirement model + input on lessons learnt
«supply»
Validation of requirements is an follow-up activity. It aids the project management to close the deal with customer.
«resource» project team and stakeholders

Figure 14: Requirement validation process diagram

In practice, the requirement model is validated by creating the development model based on the analyzed requirement model. This is a joint effort of the developers, analyst, and project manager. Furthermore, there might arise a need to involve customer or other stakeholders to support the process and adjust certain aspects.

This mapping of requirement model and development is discussed in Chapter 6. UML ELEMENTS AND THEIR RELATIONS TO REQUIREMENTS. Typically developers would create embedded sequence diagrams to use cases, testers would create (system) test cases from use cases and UI designers would create flows based on use cases and user interface related requirements, etc. Diagrams that describe structural aspects (i.e. architecture) would be traced into requirement elements so each module would be responsible for fulfilling the required to functionality. If those connections were not to be found than either there would be a missing requirement or redundant code in a system

A validated model accurately pictures the system and in the process of update the project team can learn many things. Such as that the whole team can intimately understand the relation between the implementation and the customer requirement. Having a project team to work integrated for the same cause and avoiding duplicate work is a challenge in all projects especially in multi-site and technically demanding ones [32]. The requirement validation sub-process contributes enormously to the integrity of project.

Furthermore, a properly validated model gives a strong promise that the product can be built and delivered or if it actually reveals severe challenges it aids the project management to realize the risk of failure earlier in the project.

7.1.4 Change Control

There are entire books on this topic alone, managing change in a controlled manor is demanding in the pressures of project life. In the industry there is widely spread culture for NOT accepting the self-evident fact that change causes impact. Typical phenomena of this is a scope creep where for example customer pushes for scope changes and would not accept the affect on the delivery time and budget. These can be avoided if the agreement for the project specifies a change control process. An example of such a process is presented in Figure 15.

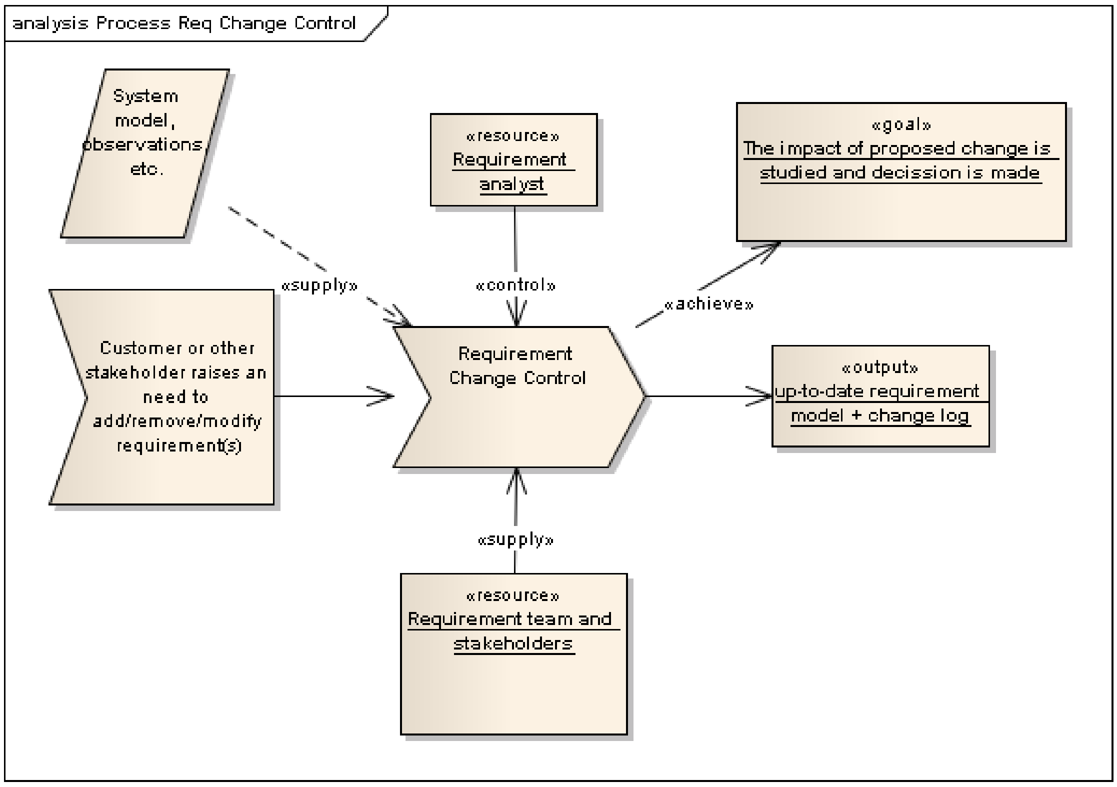

analysis Process Req Change Control
System model, observations, etc.
«resource» Requirement analyst
«goal» The impact of proposed change is studied and decission is made
«supply»
«control»
«achieve»
Customer or other stakeholder raises an need to add/remove/modify requirement(s)
Requirement Change Control
«output» up-to-date requirement model + change log
«supply»
«resource» Requirement team and stakeholders

Figure 15: Requirement change control process diagram

The activating event for change control process is e.g. customer's realization that there is valid reason to add or remove or change some of the initial requirements. Typically meeting for such purpose would be arranged and the impact of the change is estimated. Actually, UML-RM process way of working gives project team a significant help on making sound decisions. This is because requirement are mapped into use cases and software components thus change in one case/requirement can be traced into module level and the work needed to accommodate the extra work can estimated.

Also, to ensure that change can be implemented in proper fashion basic arrangement for version control over the requirement model needs to be in place.

7.2 Perceived Benefits of the UML-RM Process

The used UML-RM process solves many common problems occurring in traditional requirement management processes such as traceability. For example list based tools rely on requirement ids to be attached to design and implementation components but these ids have to be manually inserted into design documents making linking prone for breaking. UML-RM has strong and easy to follow inter-connectivity between requirement, design, and software components. This allows managers to check which implementation component is responsible of what requirement. This again reduces wasted effort on the project and makes teams and product more integrated.

Modeling also allows team to check the design before costly implementation work is started reducing risk and wasted effort.

7.3 Limitations of the UML-RM Process

Since this process is based on UML notation it requires a project team to understand the relevant diagrams. For example a customer is required to understand only simple use case and requirement diagrams. Addition to these two diagrams project management should also understand basic structural diagrams describing the architecture. Whereas the developers should know how to apply for example sequence diagrams to model interaction between components and class diagrams to specify the system. UML is widely taught in universities so many professionals are familiar with it. As a practical note requirement analyst might still need to act as a instructor to the customer about the use case and requirement diagram notation when performing requirement elicitation.

UML-RM is applicable to any implementation language and fitting for many development processes and types of projects. The presented process is a custom fusion of existing Use Case driven (ICONIX) and SysML methodologies. It applies well in the software development areas were complexity is high for example multimedia system projects.

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