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A COMPARISON OF SOFTWARE PRODUCT LINE SCOPING APPROACHES

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During the past decade a number of methods and techniques for software product line scoping have been developed. Although their basic goal is the same, when it comes to details it is often hard to see what they have in common, where they differ and what their strengths and weaknesses are. This makes it difficult for the user to decide when and how to use them because these methods and techniques sometimes describe the same concepts and activities with different terminologies and, more often than not, by that the activities and tasks defined in them do not exactly match with each other and their inputs/outcomes are not clearly defined. In this paper, we compare and analyze the mainstream approaches to software product line scoping, deduce their essential components and develop them into a unified approach that can be easily referred to and utilized by the user companies planning to launch product lines.

Keywords: Software product line; product line scoping; software reuse.

1. Introduction

Clements and Northrop define software product line as "a set of software-intensive systems sharing a common, managed set of features that satisfy the specific needs of a particular market segment or mission and that are developed from a common set of core assets in a prescribed way" [1]. The main idea of software product line is to provide high-quality products at low costs by developing similar products via extensive reuse. Therefore, finding the commonalities of products and developing common assets that realize these commonalities are important for high reusability.

Activities for achieving these necessities start with product line scoping. Product line scoping is an important phase in product line engineering to decide not only what products to include in a product line but also whether or not an organization

should launch the product line. In other words, the scoping activities include calculating the ROI (Return on Investment) that an organization can expect to obtain by launching and operating a product line and determining, by the decision makers, whether the product line is worth investing on based on the estimated ROI. This definition has a subtle difference from that of the European ITEA project series; they define scoping as the process of bounding the domains that have reuse potential within a product line [2]. There are differences regarding what aspects (e.g., benefits from customers, costs, and time-to-market viewpoints) are considered but, it is common that benefits expected from a product line are estimated at the product line scoping phase.

According to J. Bosch [3], scoping process consists of three levels, i.e., product portfolio scoping, domain scoping, and asset scoping (besides these three levels, Fraunhofer IESE's PuLSE-Eco defines the domain potential assessment process separately [4]. As for the European ITEA project series, they propose a life-cycle scoping [5]). Product portfolio scoping aims at determining products and their features that should be included in a product line. Domain scoping aims at defining the functional areas and subareas of the product line domain, while asset scoping aims at identifying assets with costs and benefits estimation from them.

However, no single scoping approach addresses all three levels completely [6]. In addition, although the basic goal of these approaches is the same, when it comes to details, often it is not easy to see what they have in common and where they diverge and what their strengths and weaknesses are, thereby making it difficult for the user to decide when to use them and how to use them. This is because these methods and techniques sometimes describe the same concepts and activities with different terminologies and more often than not the activities and tasks defined in them do not exactly match with each other and inputs/outcomes of the activities are not clearly defined.

This paper is our endeavor to solve these problems in the existing product line scoping approaches. For this, we first refer to the disciplines of marketing science and the manufacturing industry for deriving what activities should be conducted for scoping. And we compare and analyze the mainstream approaches to software product line scoping. Through this study, we deduce the essential components and integrate them into a unified approach that can be easily referred to and utilized by the user companies planning for a software product line. In addition, the unified approach[a] is harmonized with the international standards (i.e., ISO/IEC 12207 and 15288) in both process and general terminologies so that organizations can apply these product line principles to product line scoping with the help of the unified approach.

[a]In this paper, we define 3 levels of scoping, which is defined in [3, 25] as three main subprocesses because each of them provides inputs to the next level of scoping. Following IS12207/15288, we view a process as having the hierarchy of process-subprocess-task and accompanying purpose and outcomes. So scoping process consists of the three subprocesses: product portfolio scoping, domain scoping, and asset scoping.

This paper is organized as follows: In Sec. 2, we survey the scoping concepts and the mainstream approaches to product line scoping. In Sec. 3, we present the framework for comparing the mainstream approaches. In Sec. 4, we conduct an in-depth analysis to solve the problems in the existing approaches discussed in the Introduction. In Sec. 5, a unified product line scoping approach is developed based on the results of Secs. 2, 3 and 4. And in Sec. 6, an example of applying the unified approach is provided. Finally, in Sec. 7, we conclude our paper by mentioning the contributions of the paper and future research directions.

2. Overview of Product Line Scoping

CMU/SEI defines scoping as a process for defining the scope and they consider that the scope is a way to examine whether the product line is economically viable [1]. In a framework for product line practice of CMU/SEI, scoping is included in Technical Management practice area. Fraunhofer IESE conducts scoping in PuLSE-Eco, one of the Technical Components of PuLSE^{TM} [8] and in European ITEA project series, scoping is covered System Family Scoping and System Family Economical Analysis process in their reference model (according to the classification of [6, 7], product line management & scoping).

Scoping defined by CMU/SEI does not provide concrete tasks for product portfolio and asset scoping. Analysis of market and competitors is conducted in 'Building a Business Case' practice of Organizational Management practice area and these results are input to scoping practice. They define that a business case can serve two purposes in a product line. The first is to justify the effort to adopt the product line approach for building systems. The second is to decide whether or not to include a particular product as a member of a product line [1]. As for PuLSE-Eco of Fraunhofer IESE, tasks for product portfolio scoping process are defined in Product Line Mapping [4, 23] process, but they also do not provide concrete tasks for market analysis [4]. On the other hand, European ITEA project series also provide traditional methods of product portfolio definition and management [2, 6], but product line specific portfolio definition tasks are not defined. In conclusion, all three groups do not provide concrete tasks for product portfolio scoping.

On the other hand, all three groups provide tasks for domain scoping. Almost all scoping process of CMU/SEI are for domain scoping and as for PuLSE-Eco of Fraunhofer IESE, most tasks of product line mapping and domain potential assessment are related to domain scoping. In the case of European ITEA project series, they introduce tasks defined and applied in BOSCH, and so on except for overlapping parts with PuLSE^{TM} [5].

As for asset scoping, Fraunhofer IESE's PuLSE^{TM} define concrete tasks, but the purpose of asset scoping is not to decide whether an organization launches product line but mainly to decide which assets are developed. In PuLSE-Eco, they define quality model ([9] proposes a meta-model for defining quality model) for estimating costs, benefits and so on. Quality model supports method for defining metrics to

estimate QA (quality attributes to measure process quality: effort, product quality: reliability/usability/efficiency/etc.). Scoping process of PuLSE^{TM} includes tasks to estimate these QAs. SIMPLE and COPLIMO [10, 11] provide costs and benefits estimation methods due to introducing product line (refer to *building a business case* practice of [1]).

We can understand well the important points of each scoping approach by analyzing the classification of scoping for each approach. PuLSE^{TM} classifies scoping as one of the technical components, CMU/SEI's scoping is included in Technical Management practice area, and European ITEA project series [6] defines scoping as the first process of domain engineering. Technical Components of PuLSE^{TM} function to provide process, methods, tools, and experiences related to product line practice. Domain engineering of European ITEA project series has the same responsibility with technical components of PuLSE^{TM}. On the other hand, as an area to engineer the creation and evolution of both core assets and products [1], practices in technical management practice area of CMU/SEI are similar to management activities of PuLSE^{TM} or European ITEA project series' domain engineering (Technical Components of PuLSE^{TM}) and application engineering (deployment phase of PuLSE^{TM}) in a technical aspect. CMU/SEI distinguishes technical management and organizational management practices. Because scoping is included in technical management area, the focus of scoping process is on domain scoping. And the remaining levels of scoping are conducted in Organizational Management practice area. Also, software product line practice patterns that CMU/SEI proposes are similar to customization in PuLSE^{TM} that is conducted before scoping.

3. The Comparison Framework

Figure 1 describes our comparison framework to solve the three problems and compare the existing scoping approaches.

In our comparison framework, we first define initial product line scoping process based on the purpose of scoping with three levels of scoping and general terminologies (❶). Initial outcomes for verifying achievement of defined purposes, inputs for producing outcomes, and tasks for transforming inputs to outcomes are defined in order. And we analyze existing scoping approaches to solve incompleteness problem (❷). The initial product line scoping process is revised based on this. And then we analyze thoroughly what subprocesses, inputs, tasks, and outcomes are defined and but not dealt with in the existing approaches including terminology differences for solving inefficiency problem (❸).

The initial product line scoping process might be revised several times during this activity. After that, we arrange the comparison results revealing three problems — incompleteness, inefficiency, terminology — in four aspects, input, task, outcome, and terminology (❹). At last, we revise our unified product line scoping process using comparison results (❺). The unified process definition for product line scoping is described using process elements, i.e., purpose, inputs, agents, tasks,

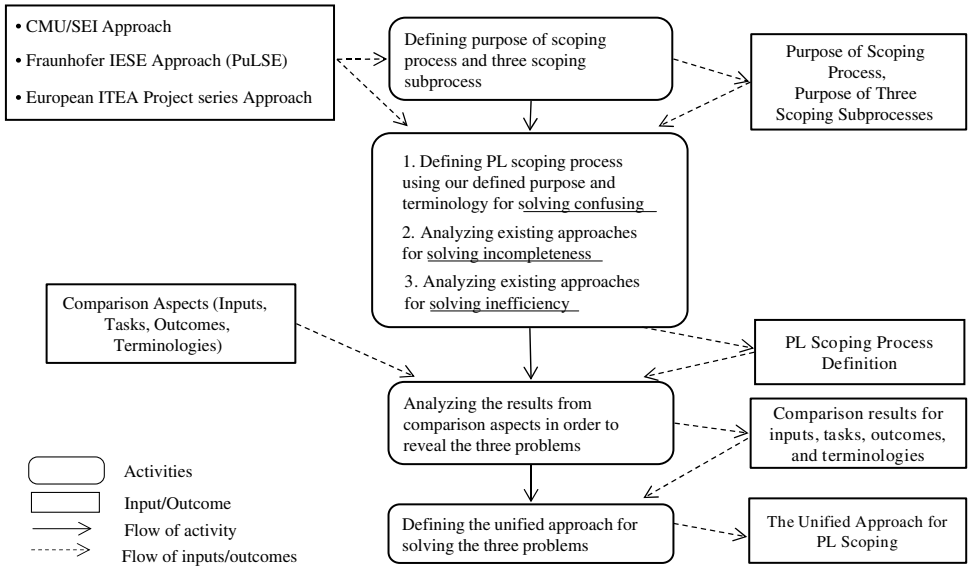

Fig. 1. The comparison framework.

work products, and outcomes. In this section, we define general terminologies, process documentation elements, and comparison aspects.

3.1. *Terminology*

In this subsection, we define the general terms related to product line scoping that will be used in this paper. Some terms are used after refining them and some others are defined anew to avoid confusion. The following are the terms to be refined or defined, or need to be used carefully:

- **Scoping:** Decision making activities for senior managers to choose whether to launch a product line after they calculate reusability and ROI by applying product line. Scoping does not include management activities such as product portfolio evolution.
- **Core asset:** A reusable artifact or resource that is used in the production of more than one product in a software product line. A core asset may be architecture, a software component, a domain model, a requirements statement or specification, a document, a plan, a test case, a process description, or any other useful element of a software production process [12].
- **Core asset base:** The complete set of core assets associated with a given software product line [12].
- **Functional areas:** Areas and their functionalities with high potential of reusability among product line members.

- **Domain:** A set of systems or functional areas within systems, that exhibit similar functionality [13].
- **Cost and benefit function:** We emphasize cost and benefit estimation due to the introduction of a product line in order to agree on the original objective of scoping instead of using terminology such as economic analysis, quality model, characterization matrix, etc.

3.2. *Purposes of product line scoping and their subprocesses*

The purposes of product line scoping are (1) to decide which product parts can be reused systematically, and (2) to provide information about how much cost and benefit will be consumed and gained for the decision makers. Therefore, we add a new type of scoping, business case scoping, for achieving the second purpose. The following three subprocesses of the product line scoping process build on each other. The purposes of these subprocesses are defined as follows:

- **Product portfolio scoping** determines the product portfolio definition, that is (1) the products that the product line organization should be developing, producing, marketing, and selling; (2) the common and variable features that the products should provide in order to reach the long and short term business objectives of the product line organization, and (3) a schedule for introducing products to markets.
- **Domain scoping** identifies and bounds the functional areas that are important to the envisioned product line, and to provide sufficient reuse potential to justify the product line creation. Domain scoping builds on the definitions of the product categories produced by product portfolio scoping.
- **Asset scoping** is used to identify reusable assets and calculate the cost/benefit estimated from each asset in order to determine whether an organization should launch a product line.

Figure 2 is a representation result of the relations among these product line scoping subprocesses using the notations of IDEF0 [15]. IDEF0 notations are good for representing a process using data and requirements because they make it possible to represent inputs, outputs, mechanisms, and controls other than activity flows.

As depicted in Fig. 2, product portfolio scoping is conducted by people who have overall knowledge about products, customer needs, competitors, and market & technology trends, and by people who can authorize strategic decisions about which products will be produced within a product line and under what strategies. Using this product portfolio definition, domain experts who have in-depth knowledge about products, and developers who can review the technical feasibility analyze the domain, functional areas, and features, and map the refined common & variable features to functional areas. The mapping results of functional areas and features are decomposed possible assets in asset scoping, and the ROI is then estimated using the available measurement data related to the assets or features.

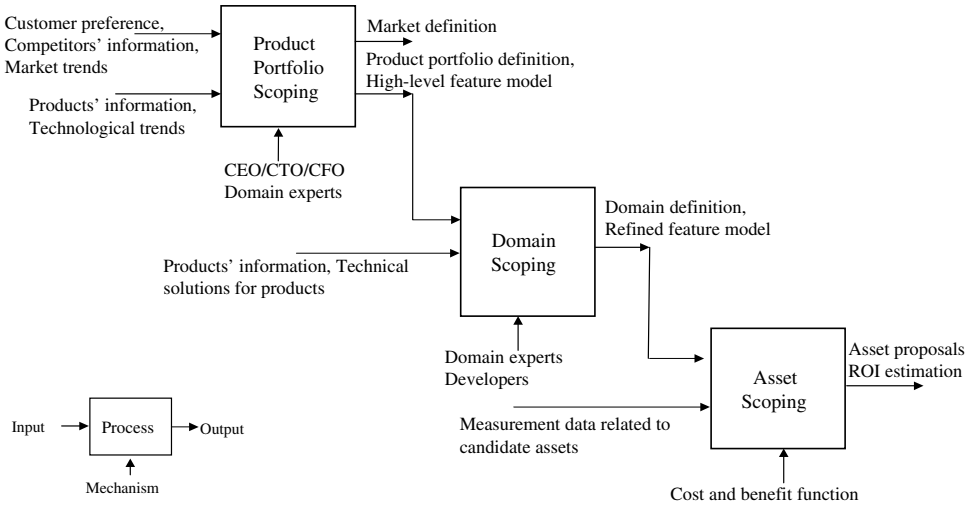

Fig. 2. Product line scoping subprocesses in the Unified Approach.

3.3. *Comparison viewpoints*

In this paper, we chose process documentation elements — purpose, inputs, outcomes, and subprocess/activity/task — based on the process information guideline [16] and process construct of ISO/IEC 12207 and 15288 [14]. But as we already mentioned, we are trying to solve the three problems, (1) incompleteness, (2) inefficiency, and (3) confusion. The first and second problems can be solved by analyzing inputs, outcomes, and tasks. And the third problem is related to terminology and we have to reveal the terminology differences in order to solve it. Therefore, we chose four comparison aspects: terminology, outcomes, tasks, and inputs. We excluded purpose from comparison aspects because most researchers agree on the purpose of scoping and on each level.

4. Comparison of the Approaches to Product Line Scoping

In this section, we describe the comparative analysis results of the existing approaches from the viewpoints of (1) terminology, (2) outcomes, (3) tasks for deriving outcomes, and (4) inputs.

4.1. *Terminology comparison*

Organizations and researchers have had difficulties in the application or research of product lines because existing approaches used different terminologies. For example, CMU/SEI defines core assets as reusable artifacts or resources used for producing more than one product within a software product line [12].

The European ITEA project series defines domain assets as reusable development artifacts created during the domain engineering processes [6] and depicts that

Table 1. Terminology comparison.

The unified approach	SEI product line practice framework	Fraunhofer IESE PuLSE	European ITEA project series
Product line	Product line Business unit	Product line	Product line System family
Domain engineering	Core asset development	Product line infrastructure construction	Domain engineering Product family engineering (PFE) Development artifact Platform Engineering (PLE)
Application engineering	Product development	Instantiation	Application engineering
Product line scoping	Product line scoping	Product line scoping	System family scoping Product family scoping Product management and scoping [6]
Core asset	Core asset (But core asset and asset are not explicitly distinguished.)	Reusable asset Common platform asset	Domain asset Platform asset Product line asset
Asset		Asset	Software product line infrastructure
Core asset base	Core asset base	Product infrastructure usage	Platform (Software platform)
Cost and benefit function	Cost and benefit functions	Quality model	
Feature	Feature	Feature Characteristic (before)	
Functional area (functional sub-area)		Domain (sub-domain)	Domain (sub-domain)

synonyms are platform assets and product line assets. CMU/SEI [21] classifies the alternative terminology of software core assets by platform. In fact, in the European ITEA project series platform (software platform) is a set of software sub-systems and interfaces so that family of products can be efficiently developed [6]. Therefore, we can refine that the synonym of core asset is platform asset and platform is core asset base that is a complete set of core assets related to a software product line [12]. But, we can regard platform asset as a subset of all core assets.

Table 1 shows the terminology comparison results for the three mainstream approaches and the unified approach (Terminologies of the unified approach are defined in Sec. 3.1).

4.2. *Outcomes of the product line scoping process*

In this subsection, we describe the analysis results of outcomes focusing on their contents. To make the best use of the unified approach, we arranged the results

Table 2. Comparison of the outcomes of the three mainstream approaches.

The unified approach	SEI product line practice framework [1]	Fraunhofer IESE PuLSE^{TM} [4]	European ITEA project series ([6])
Market definition			
Product portfolio scope definition	[O_S_PLS] Product line strategy	[O_F_PM] Product map [23]	[O_E_PP] Product portfolio
— High-level feature set	[O_S_APM] Attribute/ product matrix	[O_F_POPFM] Prioritized/ Optimized Product feature matrix	[O_E_DS] Domain specification
— Domain scope definition	[O_S_PLS] Product line scenarios		
High-level production plan		[O_F_PRP] Product release plan	
— Estimated ROI from product line	[O_S_AP] Asset portfolio [18]	[O_F_QPFM] Quantified product feature matrix	[O_E_AP] Asset proposals
— Asset proposals	[O_S_IA] Investment analysis [18]		

using the outcomes. Table 2 shows the placement results for outcomes with similar contents.

As for CMU/SEI, because some elements that consist of outcomes for product portfolio scoping and asset scoping are produced from other practice areas, a scoping practice needs to continuously interact with other practice areas for taking related outcomes. However, they do not describe what kinds of outcomes should be input from or output to another practice area. The following summarize the contents of the outcomes of the three approaches in Table 2:

- [O_S_PLS] Product line strategy: business goals, current and potential future products descriptions, essential product line assets, and coarse-grained schedule that aligns overall product line strategies
- [O_S_APM] Attribute/product matrix: "attributes that derive the market are listed vertically on the left side of the matrix; the different products are listed horizontally across the top of the matrix; the value for the attribute of each product is listed where the attribute column and product row intersect [1]"
- [O_S_PLS] Product line scenarios: descriptions for user or system interactions that are common/unique to all products in product line
- [O_S_CRBE] Cost/benefit estimation: initial costs for developing product line's asset, costs for fielding initial products, costs associated with using assets in developing products, and benefits of switching to the product line approach (e.g., reduction in personnel required for integration, reduction in time-to-market, etc.) [1]
- [O_F_PM] Product description (Initial product map): appropriate products for the product line, their potential market, their high level features, and the rough release plan

- [O_F_POPFM] Prioritized/Optimized Product feature matrix: Functionalities that are generally used together in the product line, descriptions for functionalities, and their features prioritized and optimized by using marketing-oriented models.
- [OF_PRP] Product release plan: A graphical representation of the release dates of the products as well as their interdependencies.
- [O_F_QPFM] Quantified product feature matrix: Product feature matrix extended with the existing available assets is quantified using a quality model which is defined for measuring economic factors.
- [O_E_PP] Product portfolio: a simple list of products along with their major features and functionalities (same as product map of PuLSE-Eco)
- [O_E_DS] Domain specification: domain description (responsibilities of the domain), domain defining rules (decision criteria about inclusion and exclusion for domain membership and the logical relationships between criteria), exemplar system selection (a set of systems or subsystems in the scope of which domain functionality occurs), domain settings (a generic set of life cycle settings identified whining the exemplar system selection), domain context (the relation of the domain of focus to other domains), domain genealogy (information about the evolution, historical interrelationships, and dependencies among systems within a domain), feature association (for describing variabilities and commonalities within a domain more explicitly) [5]
- [O_E_AP] Asset proposals: Refined functionalities and the calculation of economic benefits

While there are common outcomes among the three approaches, each approach defines outcomes for its own as illustrated in Table 2. The outcomes of the unified approach have been defined by consolidating those of the existing approaches. For example, market definition contains part of product line strategy such as market and product line strategy, viable market observation results. And essential product line assets and coarse-grained schedule of product line strategy are dealt with product portfolio definition, one of outcomes of the unified approach. Definitions relevant to outcomes of the unified approaches will be discussed throughout Sec. 5.

4.3. *Tasks in product line scoping*

While CMU/SEI does not explain scoping by classifying the subprocesses, Fraunhofer IESE and the European ITEA project series approach describe three levels of scoping. In CMU/SEI's product line practice framework, scoping is included in the Technical Management practice area. The first specific scoping task is to examine existing products for identifying types of commonality and the differences of a potential product line. And practitioners develop essential product line assets that are sufficient for satisfying a product line goal and identify the main attributes (i.e., features) related to product line. They develop products line scenarios for defining common attributes among products within the product line [1].

In the European ITEA project series, scoping is dealt with in Product Management & Scoping within the software product line engineering framework [6] (this is similar to Product Management of [2]). While Fraunhofer IESE's PuLSE-Eco defines tasks focusings on domain scoping and asset scoping, the European ITEA project series describes the overall guidelines for three subprocesses of product line scoping [2, 6]. Also, they provides organization-specific scoping methods such as those used ins Philips, Siemens, Nokia, and so on (e.g., scoping in the presence of multiple domains and product populations). We analyzed the research results of the European ITEA project series through public results and the dissemination of ESAPS/CAFÉ/Family [2, 6, 7].

4.3.1. *Product portfolio scoping*

As for CMU/SEI and Fraunhofer IESE's PuLSE^{TM}, product portfolio scoping is not fully covered in the scoping process, but some tasks of domain scoping are related to product portfolio scoping. Also, these two approaches focus on the technical aspects of scoping, so they exclude tasks related to marketing science. On the other hand, the European ITEA project series explains product portfolio scoping and provides detail guidelines for it [2], but they do not define concrete tasks. Figure 3 depicts analysis results for the three approaches. A dotted line in the figure indicates

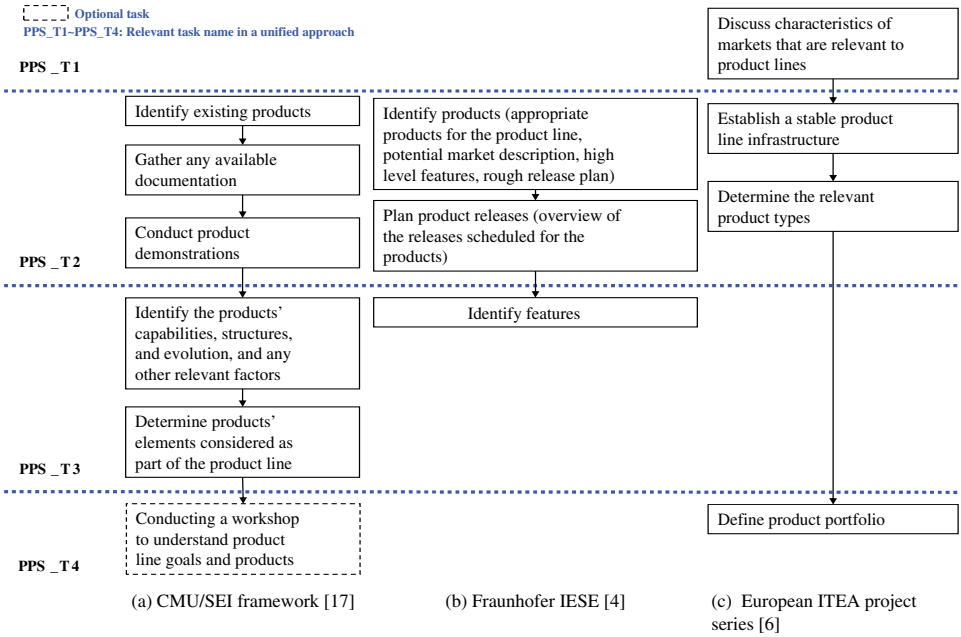

Fig. 3. Comparison of product portfolio scoping tasks.

grouping results by the product portfolio scoping tasks of an initial product line scoping process.

In the CMU/SEI approach, the Building a Business Case practice of the Organizational Management practice area defines a product portfolio, and the Market Analysis practice provides tasks for gathering business intelligence, competitive studies and assessments, market segmentation, customer plans and strategies, and the integration of this information into a cohesive business strategy and plan [17]. Practitioners gain necessary knowledge of single products and a deep and broad understanding for domains from the Understanding Relevant Domain practice of the Software Product Line practice area. They decide what products will be excluded and included from these business cases and domain knowledge. The CMU/SEI approach discriminates scoping activities from the analysis of market/competitors/customers in deciding on a product portfolio and for estimating costs and benefits.

The production plan [19], one of the outcomes from CMU/SEI's product portfolio scoping, captures how a product line organization builds any product, and specifies the following: inputs needed to build a product; activities that result in a completed product; roles and responsibilities of the product developers; interactions needed with other groups in an organization; and the schedule and resources associated with building the product. Through this, we can understand that the scoping of CMU/SEI only achieves the first purpose we defined already.

Fraunhofer IESE's PuLSE-Eco focuses on two levels, domain scoping and asset scoping — product portfolio scoping is seen as a part of marketing science and thus is only partially addressed [4]. However, the European ITEA project series defines the core of product management as a product portfolio definition and ongoing management [6]. Product management also includes management activities besides product portfolio scoping. Also, they propose four major dimensions of product line market aspects necessary to conduct product portfolio scoping for analyzing relations with business aspects [6]: product definition strategy, market strategy, product line life-cycle, and the relation of product line strategy and product line engineering.

As Fig. 3 depicts, the unified approach combines and redefines the comparison results. According to the predefined purpose, inputs, and outcomes, the unified approach defines tasks necessary to convert inputs into outcomes while fulfilling the purpose. We will give descriptions for the tasks of the unified approach throughout Sec. 5.

4.3.2. *Domain scoping*

As we already mentioned, CMU/SEI does not discriminate the scoping levels in a scoping practice, but they do define the related tasks. As for the European ITEA project series, they present domain scoping of PuLSE^{TM}, research results of the ESAPS project, without defining domain scoping activity separately [6]. So, in Fig. 4, we choose the BOSCH approach among the research results of the European ITEA project series [5].

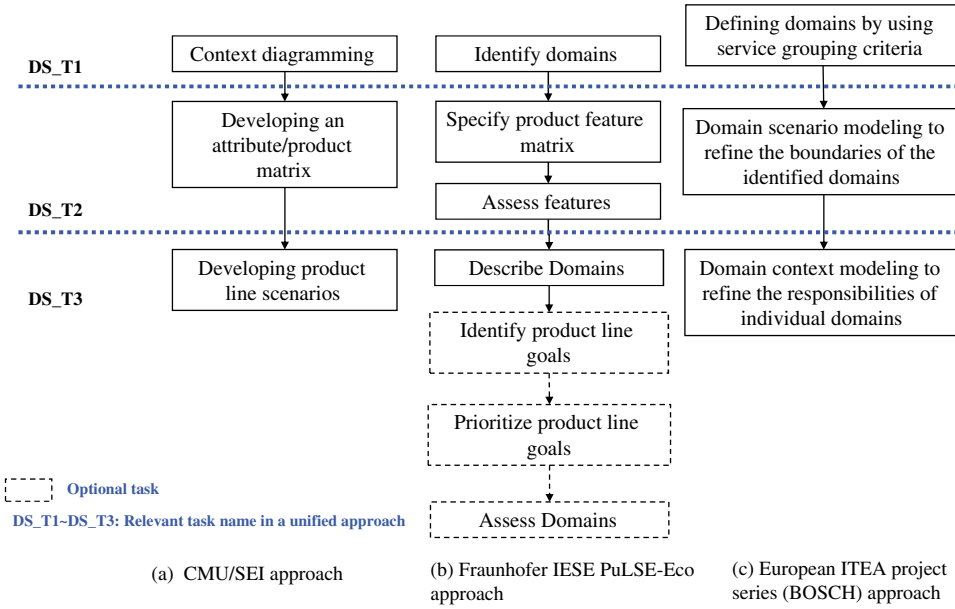

Fig. 4. Comparison of domain scoping tasks.

Fraunhofer IESE's PuLSE-Eco focuses on domain scoping and asset scoping [4]; but some initial tasks of product line mapping are included in product portfolio scoping (in product line mapping, *identify products* and *product release plan* tasks [4] partially address this). PuLSE-Eco provides in-depth descriptions for domain scoping, asset scoping, and input/outcomes for each task. PuLSE-Eco was tailored in many industrial contexts [4], and they classify the customization factors that give significant influence on scoping based on these experiences. PuLSE-Eco provides the scoping part/activity influenced by each customization factor. So practitioners can tailor the scoping process according to the characteristics of an organization.

The BOSCH case of the European ITEA project series developed different domain description approaches, a meta model for domain specification, and an approach based on service-grouping criteria for domain evaluation [5]. It describes a domain using services that represent a single capability of a domain.

All three approaches define the domain scoping process in detail. But, there is a tendency to use the term *domain* in a confusing way. Fraunhofer IESE defines domain as a conceptual unit of functionalities that are generally used together in a product line [4]. But, the original meaning of the term *domain* denotes or is used to group a set of systems of functional areas, within systems, that exhibit similar functionality [13].

In domain scoping, *domain* means the boundaries drawn from analysis results of the characteristics of products within a product line such as their common and variable features. PuLSE-Eco defines that the goal of an *identify domain* task is to find internal and external sub-domains of a product line [4]. In the European

ITEA project series, the BOSCH approach, developed in the ESAPS project, and CMU/SEI also use the term *domain* differently than with the general meaning. In product line, *domain* means functions that are generally used together within the domain that the product line will be applied to. So it is proper to use *functional area* instead of *domain*. A function area might have several functional sub-areas. The unified approach combines and refines tasks in accordance with the comparison results and uses functional areas/sub-areas instead of domain.

4.3.3. *Asset scoping*

Asset scoping is a subprocess of product line scoping process that has significant differences among scoping approaches like product portfolio scoping. While CMU/SEI does not deal with asset scoping in its scoping practice, Fraunhofer IESE and the European ITEA project series defined tasks for it. However, in spite that the purpose of asset scoping is to estimate the ROI for a product line using defined cost and benefit functions, they do not provide sufficient tasks to collect the necessary information. Figure 5 shows the results of comparing the three approaches. In Fig. 5, the dotted line is left unsettled because it is difficult to assign to one grouping.

The tasks and outcomes of the CMU/SEI approach in Fig. 5 are extracted from the 'Building a Business Case' practice related to asset scoping [1]. CMU/SEI's attribute/product matrix is similar to the product feature matrix of Fraunhofer IESE's PuLSE-Eco. While PuLSE-Eco conducts asset scoping in reuse infrastructure scoping and updates the product feature matrix, adding the cost and benefit estimation expected from a product line and it defines concrete tasks, CMU/SEI

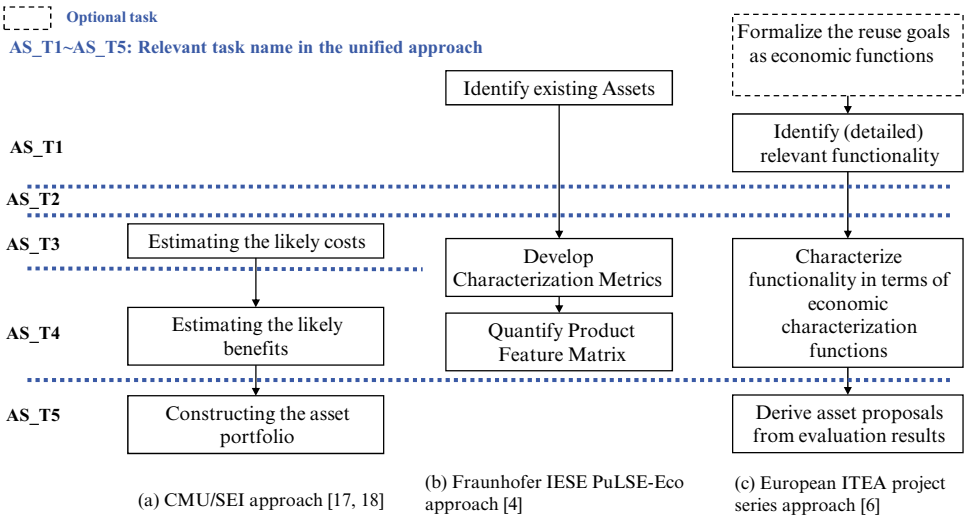

Fig. 5. Comparison of asset scoping tasks.

does not present concrete tasks. CMU/SEI provides method for analyzing investment of software assets for product lines [18].

The European ITEA project series defines asset scoping as a process for defining the initial aggregations of functionality from a ROI perspective and a starting point for the software architecture from a conceptual perspective [6]. They separate business aspects related to ROI calculation from product line economics [6]. But they present summarized tasks of PuLSE-Eco's reuse infrastructure scoping as concrete tasks for asset scoping.

The unified approach defines tasks for estimating costs for adapting existing assets and developing new assets respectively. And expected benefits by developing assets are estimated but not limited in the costs (i.e., our approach also considers benefits from the point of productivity, time-to-market, and etc.).

4.4. *Comparison of inputs*

Table 3 compares the inputs of the three approaches and their contents. To make the best use of a unified approach to be introduced in Sec. 4 we arranged the results using defined inputs of the unified approach.

Table 3. Comparison of the inputs of the three mainstream approaches.

The unified approach	SEI product line practice framework [1]	Fraunhofer IESE PuLSE™ [4]	European ITEA project series ([6])
Market information	[I_S_BC] A business case (from Building a Business Case practice) [I_S_MA] Market analysis results (from Market Analysis practice)		[I_E_MD] Market definition
• Information collected from existing products • High-level set of features	[I_S_DM] Domain models (from understanding relevant domains)	[I_F_FD] Feature description [I_F_AD] Architecture documentation [I_F_TR] Technical roadmap [I_F_UM] User manual	Same as the PuLSE™
Assets from existing single products		[I_F_RC] Reusable components [I_F_AD] Architecture documentation [I_F_TR] Technical roadmap	[I_E_BKE] Background knowledge and experience
Cost and benefit functions and/or other information from current practice	[I_S_EC] An economic case (from Building a Business Case)	[I_F_AMD] Available measurement data	

The following are descriptions for the contents of each input:

- [I_S_BC] *Business case*: the effort required to adopt the product line approach for building systems and the rationale for deciding product members of the product line.
- [I_S_MA] *Market analysis results*: business strategy for moving from single systems development to product line engineering.
- [I_S_EC] [I_S_MA] *Economic case*: the costs and benefits of the current approach business versus those of the business based a product line approach.
- [I_E_MD] *Market definition*: Product definition strategy, market strategy, product line life-cycle, the relation of product line strategy and product line engineering.

There are gaps and among the inputs of the three approaches. The inputs of the unified approach are defined by combining and refining the comparison results in accordance with the outcomes and tasks of the unified approach. Our approach fills gaps in between tasks and unifies same terms, tasks, or concepts that are described in the different forms.

5. A Unified Approach

We have described the comparative analysis results for the existing scoping approaches. Through this, we revealed that most of the existing approaches exclude marketing science from the scoping process, and the tasks for deciding on a product portfolio and estimating the ROI expected from applying a product line are not defined concretely unlike the approaches of the manufacturing industry [2, 20]. In this section, we present a unified approach that consists of purposes, outcomes for validating the achievement of purposes, inputs necessary to produce outcomes, and tasks for transforming inputs into outcomes. The unified approach is defined to reflect the comparative analysis results and to solve the problems in the pervious works that were mentioned in Introduction.

5.1. *Product portfolio scoping*

The outcomes produced from product portfolio scoping are as follows:

- *Market definition.* Market and product line strategy, viable market observation results (through analysis results of customer groups, current or potential competitors, trends of prices, buying patterns, usage patterns, and technology [22]).
- *High-level production plan.* This plan defines products that are being produced currently (and, therefore, will be developed as soon as the product line is launched), in the near future, and the distant future.
- *Product portfolio scope definition.* This outcome includes the products that will be part of a product line, their externally visible common and variable feature sets, and the established schedule for market introduction.

The following tasks are necessary to produce outcomes from the provided inputs.

- PPS_T1: *Ensure a viable and focused market definition.* The definition of a product portfolio is at the heart of product line scoping. Only a focused market definition providess a basis for establishing a viable product line.
- PPS_T2: *Identify products.* After a market has been defined, the product portfolio can be characterized by a simple list of products along with their major features. In order to determine the right products, they need to be analyzed according to their market position. Information about the products may be gathered from internal (e.g., domain experts) and external resources (e.g., outside experts of component vendors).
- PPS_T3: *Analyze common and variable features.* An initial description of a set of systems is produced by analyzing which features are inside or outside the product line.
- PPS_T4: *Define the product portfolio scope.* Products within the product line may compete with or be complementary to each other. The product portfolio scope definition is appropriate only when all interrelations between the products have been recognized, analyzed, and approved.

Necessary inputs for accomplishing the purpose of product portfolio scoping are as follows:

- *Market information*: Market opportunities, competitors, technology trends, customer preference, etc.
- *Other internal/external information*, which is necessary to develop and maintain an understanding and control of the product line organization as a whole such as products' information and technological trends.
- *Characteristics of products* that have major influences in defining the product portfolio.

The product portfolio as seen from a marketing point of view need not be the same as the one seen from the engineered product line. For example, existing products can be continued outside of the new platform.

The market definition produced from the first task works as a constraint to the other tasks (Fig. 6). In other words, product, common and variable features are analyzed to satisfy the market definition. The market definition is revised by management activities. Other tasks are controlled according to the result.

5.2. *Domain scoping*

Outcomes that must be produced from domain scoping are as follows:

- *Domain scope definition* including functional areas and their common and variable features is established.
- *Refined feature set.*

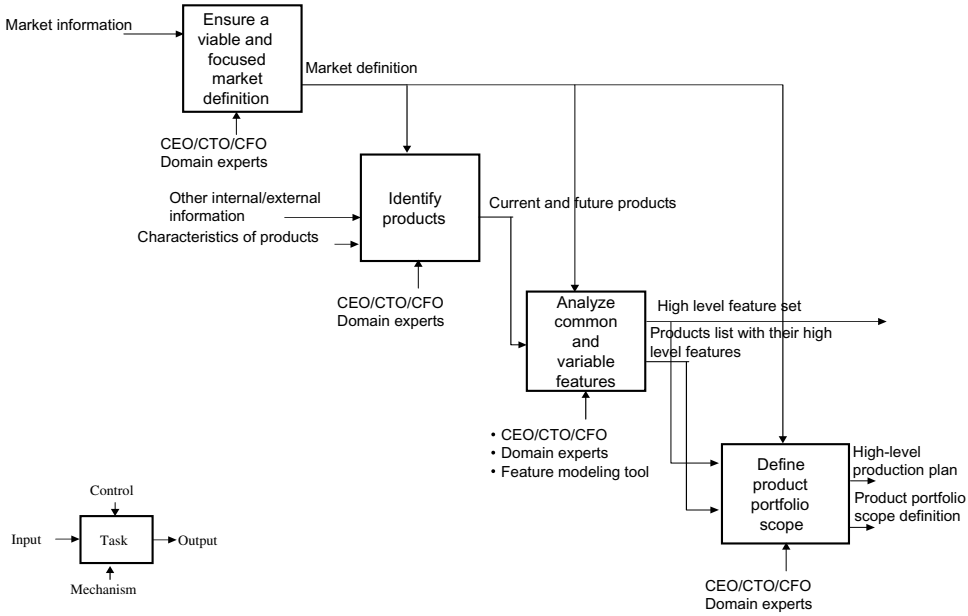

Fig. 6. Product portfolio scoping subprocess.

The following tasks are necessary for producing the defined outcomes from inputs:

- DS_T1: *Identify functional areas.* Find, analyze and categorize functions that are generally used together in the product line. Functional areas may be hierarchically defined (i.e., including sub-areas.)
- DS_T2: *Map functional areas to features.* Identified features are distributed to the identified functional areas.
- DS_T3: *Define domain scope.* Assess and select functional areas that best lend them to reuse.

Inputs necessary to accomplish the purpose of domain scoping are as follows:

- *Product portfolio scope definition from product portfolio scoping.*
- *Information collected from existing products.*

Experts who have the ability to validate the technical feasibility of functional areas and features and sufficient experience and knowledge about the products that are included in a product line classify the functional areas of the products and refine their features. Here, we use 'functional area' instead of 'domain' as the functional area is a group of functionalities that are commonly used in a product line and domain scope definition means a definition for relationships among functional areas,

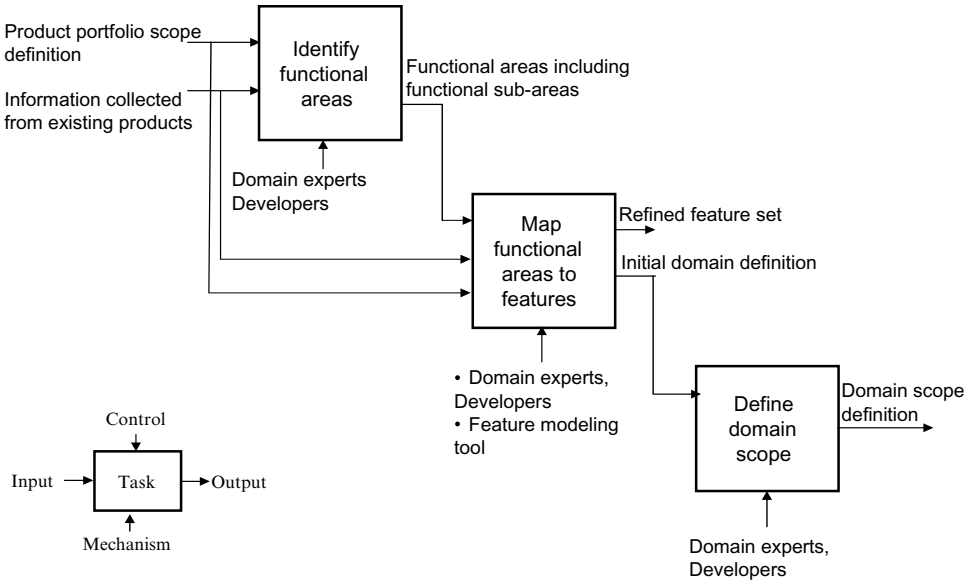

Fig. 7. Domain scoping subprocess.

products, and features. Technical verification for a domain scope definition needs to be conducted.

5.3. *Asset scoping*

Outcomes produced from asset scoping are as follows:

- *High level production plan.* A rough plan that defines which asset will be reused in which phase of the development life cycle (including the information of whether adaptation is necessary)
- *Cost/benefit estimation for each asset*
- *Asset proposals* (including functions, features)
- *Estimated ROI from a product line*

The following tasks are necessary to produce the defined outcomes from inputs:

- AS_T1: *Gather historical data from existing single products.* Identify and gather information about existing products to better understand the domain and identify potentially reusable assets.
- AS_T2: *Estimate additional effort required to adapt potential assets.* Estimate the additional effort required for adapting potential assets to the product line.
- AS_T3: *Estimate expected development effort for new products in the product portfolio definition.* Estimate the cost, effort and risk of including new products in the product portfolio. This calculation is based on the data from and/or experience of

existing related products, development constraints, systems/software attributes, and market attributes.

- AS_T4: *Estimate economic benefits from proposed assets*. Estimate the economic benefit from each asset. Benefits through implementing assets can be estimated based on domain experts' judgment and historical data.
- AS_T5: *Derive asset proposals from economic evaluation results*. Asset proposal includes assets (functional areas and features) that will be included in a product line with their quantified costs and benefits estimation results. Some assets that are estimated to have low benefit-cost ratio can be excluded in an asset proposal. We can make more than one asset proposals to find out an optimal set of products and assets.

If the product line organization has little or no background knowledge and experience to leverage in order to perform measurement-based management, this will be a significant problem in estimating the efforts required for new products. In this case, the second and third tasks (i.e., AS_T2 and AS_T3) cannot be executed; instead, a group of domain experts should be available to calculate the economic benefit, and a consensus method (e.g., the Delphi technique) can be used for decision-making. Inputs necessary to accomplish the defined purpose of asset scoping are as follows:

- *Domain scope definition* (including functional areas and their common and variable features)
- *Assets from existing single products*
- *Estimation models and/or other information of current practices*

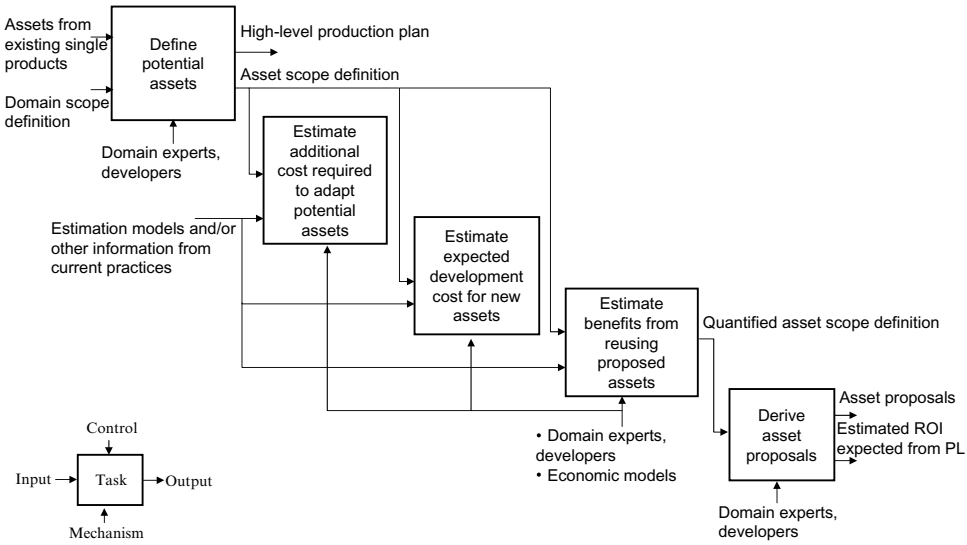

Fig. 8. Asset scoping subprocess.

In asset scoping, we decompose the functional areas of the domain scope definition into potentially reusable assets, and on the basis of the results, we estimate the ROI expected from introducing a product line. Most tasks of asset scoping are for collecting data for the costs necessary to develop or adapt assets. Based on these data, the decision makers calculate the ROI and decide the scope of the product line. As reusable assets produced in this subprocess are high-level ones, they are refined throughout the domain requirements engineering process.

6. An Example Using the Unified Approach

In this section we illustrate our unified approach through an example. We describe the example focusing on the differences with the scoping example of PuLSE^{TM} that were presented in the publications [8, 4, 19, 24]. Since Fraunhofer IESE has never presented a complete example with the results of their tasks and outcomes, we referred to scoping examples of PuLSE^{TM} that were published over the several years.

6.1. *Product portfolio scoping*

PPS_T1∼PPS_T2: In these tasks, products that will be included within a product line are determined. We chose Keypad-based Door Lock, Fingerprint-based Door Lock, and Iris-based Door Lock as current, near-future, and future products, respectively, for the Door Lock system. High level production plan is a little different from genealogy chart of PuLSE^{TM} [19] in that it has only variability in time and space.

PPS_T3: In this task we analyze high-level features of selected products in the previous task. While PuLSE uses Product Line Structure Chart [19, 25] and Characteristics Map [8], in this example we choose use case diagram for analysis.

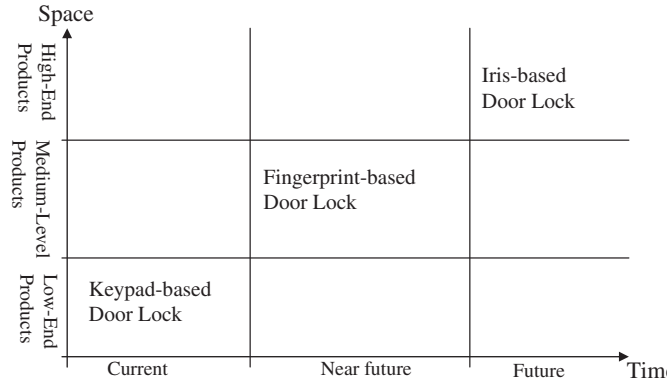

Fig. 9. High-level production plan.

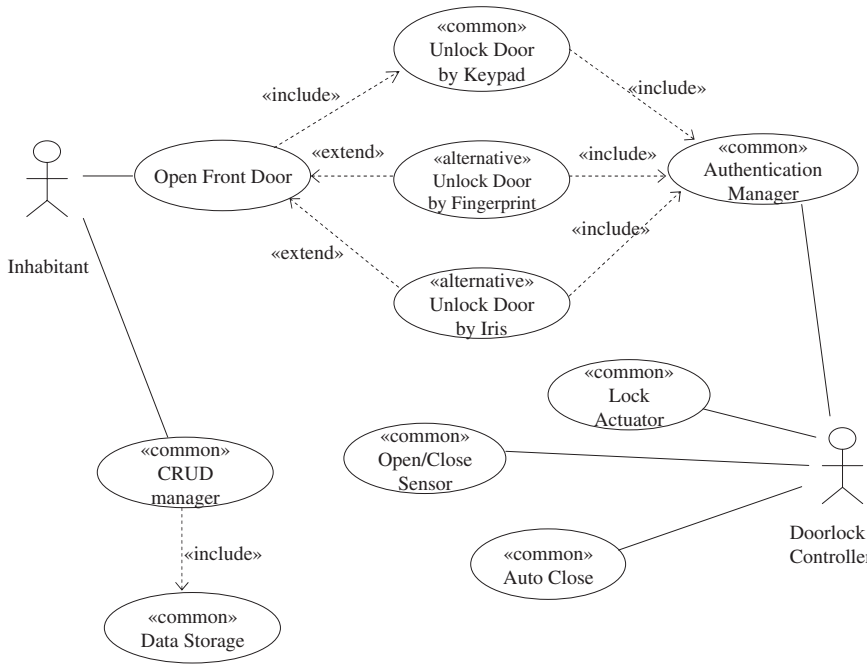

Fig. 10. Door lock system use cases and features.

Common and variable features are derived as follows:

- Common Features are Keypad, Authentication, Data Storage, Door Lock Control, Lock Actuator, and Open/Close Sensor
- Variable Features are Fingerprint_scanner and Iris_scanner

PPS_T4: From these results we defined a product portfolio scope as the following Table 4. PuLSE^{TM} did not produce a product portfolio scope definition but

Table 4. Product portfolio scope definition.

Products features	Keypad-based door lock	Fingerprint-based door lock	Iris-based door lock
Keypad	✓	✓	✓
Fingerprint_scanner	—	✓	—
Iris_scanner	—	—	✓
Authentication	✓	✓	✓
Data Storage	✓	✓	✓
Door Lock Control	✓	✓	✓
Lock Actuator	✓	✓	✓
Open/Close Sensor	✓	✓	✓

Note: ✓: required feature

characteristics map or initial product map [8, 24] are similar to our product portfolio scope definition.

6.2. *Domain scoping*

In domain scoping, we analyzed further features based on the product portfolio scope and high-level features. Since PuLSE^{TM} presents tasks, inputs, and outcomes for domain scoping in detail, there was small difference between PuLSE^{TM} and our unified approach.

DS_T1: In this task we identified functional areas for a domain and identified areas were User Interface, Authentication Manager, Data Manager, and Door Lock Control. As we already explained, we use the terms 'functional area' and 'functional sub-area' instead of 'domain' in order to avoid confusion while the product map of PuLSE^{TM} [8, 19] uses the terms such as domain (sub-domain), characteristics, and features.

DS_T2∼DS_T3: In this task we mapped functional areas to features and defined domain scope. Table 5 shows the results. Domain scope definition is similar to a product map [8, 19] (or product feature matrix [4]) of PuLSE^{TM}.

Table 5. Domain scope definition.

Functional areas/sub-areas	Feature name (Variants)	Variability dependency	Variation point name	Constraint dependency
User Interface	Keypad_inf	Common	Terminal	
	Fingerprint_scanner	Alternative	Terminal	requires_v_v (Fingerprint_inf, Fingerprint_AM)
	Iris_scanner	Alternative	Terminal	requires_v_v (Iris_scanner, Iris_AM)
Door Lock Controller	Authentication Manger	Keypad_AM	Common	Authentication Unit
		Fingerprint_AM	Alternative	Authentication Unit
		Iris_AM	Alternative	Authentication Unit
	Data Manager	CRUD Manager	Common	
		Data Storage	Common	
	Door Lock Control	Open/Close Sensor	Common	
		Lock Actuator	Common	
		Auto Close	Common	

Note: requires_v1_v2: variant v1 requires variant v2.

6.3. *Asset scoping*

In this subprocess we focused on cost and benefit estimation in order to make a decision of whether we will initiate a product line or not. Also, our focus for cost estimation is on adapting and newly developing assets. Therefore, the factors that are considered in order to estimate costs are fewer than those of PuLSE^{TM}.

AS_T1: In this task we analyzed existing and potential assets. We found out 'Keypad' 'Authentication Manager', 'Data Manager', and 'Door Lock Control' as existing assets.

AS_T2: In this task we estimated cost required to adapt existing and potential assets (*adapt_eff*). In most of cases, assets found in AS_T1 are not used as they are. Therefore, we should calculate costs for tailoring assets. In addition, Data Manager and Door Lock Controller could be reused in fingerprint-based door lock and iris-based door lock respectively after adaptation. C_1 and C_4 through C_{11} in Table 6 are the costs for adaptations.

AS_T3: In this task we estimated costs for developing new assets (*new_eff*). Fingerprint-based and Iris-based door locks are new products for this domain. C_2 and C_3 in Table 6 are the costs for new assets.

AS_T4: Whereas the cost for developing an asset is the same for different products, benefits of an asset are different from product to product. Therefore, in this example we assume we rely on domain experts' judgments for estimating the benefit of each asset, which are in the rightmost three columns of Table 6.

AS_T5: In this task we complete the asset proposal by including assets with high benefit-cost ratios and excluding assets with low benefit-cost ratios. (This result is not shown in Table 6.)

7. Conclusion

The existing product line scoping approaches used diverse terminology and representation for the same concepts and used differently defined activities/tasks and input/outcomes in spite that the goal pursued is the same. In this paper, we conducted a comparison of the existing approaches and analyzed the overlapping and disparate concepts and steps in the existing mainstream scoping approaches. We defined the scoping process as consisting of subprocesses such that each subprocess is precisely defined in terms of its outcomes, inputs, and tasks based on process definition guideline and process constructions of ISO/IEC 12207 and 15288. As the result of this investigation, we proposed a unified approach.

Most of the past approaches did not provide concrete tasks for defining portfolio and estimating ROI of asset reuse as expected in marketing science or the manufacturing industry. The past approaches provide methods or techniques [25, 26] for scoping but it is not easy to interweave them to conduct a product line scoping.

Table 6. Asset proposal for door lock system.

Products			Cost		(Required?, Reused?)			Benefit		
Functional areas		Feature Name	adapt_eff	new_eff	Keypad (r_1)	Fingerprint (r_2)	Iris (r_3)	Keypad	Fingerprint	Iris
User Interface		Keypad_inf	C_1		(1,0)	(1,1)	(1,1)	B_1	B_2	B_3
		Fingerprint_scanner		C_2	(0,0)	(1,0)	(0,0)	—	—	—
		Iris_scanner		C_3	(0,0)	(0,0)	(1,0)	—	—	—
Door Lock Controller	Authentication Manger	Keypad_AM	C_4		(1,0)	(1,1)	(1,1)	B_4	B_5	B_6
		Fingerprint_AM	C_5		(0,0)	(1,0)	(0,0)	B_7	B_8	B_9
		Iris_AM	C_6		(0,0)	(0,0)	(1,0)	B_{11}	B_{12}	B_{13}
	Data Manager	CRUD Manager	C_7		(1,0)	(1,1)	(1,1)	B_{14}	B_{15}	B_{16}
		Data Storage	C_8		(1,0)	(1,1)	(1,1)	B_{17}	B_{18}	B_{19}
	Door Lock Control	Open/Close Sensor	C_9		(1,0)	(1,1)	(1,1)	B_{20}	B_{21}	B_{22}
		Lock Actuator	C_{10}		(1,0)	(1,1)	(1,1)	B_{23}	B_{24}	B_{25}
		Auto Close	C_{11}		(1,0)	(1,1)	(1,1)	B_{26}	B_{27}	B_{28}

Note: *adapt_eff*: cost for adaptation, C: Cost, B: Benefit
new_eff: cost for developing a new asset, — : N/A
Required?: Is the feature required for a product? 1: Yes, 0: No
Reused?: Is the feature reused in a product? 1: Yes, 0: No (If a feature is not reused then it is assumed to be introduced.)

The unified approach that we proposed in this paper reflects disciplines of marketing science and the manufacturing industry and is harmonized with the process construction in International Standards. The unified approach is designed to solve incompleteness, inefficiency, and confusion found in the existing approaches and reflects comparative analysis results. Our approach fills gaps in between tasks of the three approaches and unifies same terms, tasks, or concepts that are described in the different forms. Because the comparison results provide detailed information that reflects the state-of-the-practice and the state-of-the-art, the user companies can utilize it for conducting scoping based on their existing practices or after tailoring them.

Our unified process will be useful also for developing methods and tools to support scoping process. And we will study a scenario based product line scoping method in order to align the product line scoping with an organization's product line goal.

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