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A FRAMEWORK TO EVALUATE THE CONVENIENCE OF ADOPTING A PRODUCT LINE ENGINEERING APPROACH

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A Thesis Submitted for the Degree of Doctor of Philosophy in Computer Science

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Defended on January 19, 2022

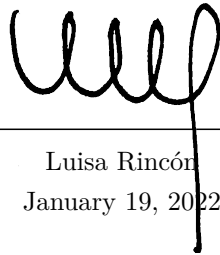
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Declaration

I hereby declare that this thesis is my original work and it has been written by me in its entirety. I have duly acknowledged all the sources of information which have been used in the thesis.

This thesis has also not been submitted for any degree in any university previously.



Luisa Rincón
January 19, 2022

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Abstract

Product Line Engineering (PLE) may be an attractive alternative for many organizations as its inherent advantages can bring such benefits as reduced costs, reduced time to market, and improved quality. However, as with any organizational change, adopting a PLE approach implies considering consequences, side effects, and minimum requirements that potential adopters would need to anticipate before deciding whether or not to adopt a PLE approach.

The goal of this research was to conceptualise how organizations could systematically evaluate whether a product line engineering approach would be convenient for their organization. To this end, this research followed a design-science methodology to elaborate and evaluate a *framework for evaluating organization's motivation and Preparation for adopting product LInES (APPLIES)*.

Eight empirical evaluations were conducted to evaluate **APPLIES** in terms of its ease of use, content pertinence, perceived usefulness, intention to use, and potential improvements. The evaluations were defined using a complementary multi-method design which included both academic and industrial points of view.

In general terms even if the **APPLIES** framework is far from perfect its critical evaluation returns promising results: respondents believe that **APPLIES** provides useful information and they would recommend it to the target audience: people interested in evaluating the convenience of adopting a PLE approach. **APPLIES** is also found useful for identifying an organization's current conditions with regard to adopting product lines: it helps to identify which factors organizations should improve, and provides information on elements to be considered before adopting a PLE approach. Furthermore, all participants of the evaluations that used **APPLIES** were able to use the tool autonomously to evaluate an organization's motivation and preparedness for adopting a PLE approach. In conclusion the framework offers a ready-to-use solution that makes it easier for newcomers to autonomously evaluate the convenience of adopting a PLE approach in their organizations.

Finally, before concluding, this thesis presents recommendations that can be used to further develop **APPLIES** in the future as a result of the researcher's analysis and reflection on the evaluation results, as well as suggestions collected from the participants of the evaluations.

Keywords: product line engineering adoption, decision-making for adopting product lines, empirical evaluation.

Traduction française du résumé

L'ingénierie de ligne de produits (PLE en anglais) peut être une alternative attrayante pour de nombreuses organisations car ses avantages inhérents peuvent apporter des bénéfices tels que la réduction des coûts, la réduction du temps de mise sur le marché et l'amélioration de la qualité. Cependant, comme pour tout changement organisationnel, l'adoption d'une ligne de produits implique de prendre en compte les conséquences, les effets secondaires et les exigences minimales que les adoptants potentiels devraient anticiper avant de décider d'adopter ou non cette approche.

L'objectif de cette recherche était de conceptualiser la manière dont les organisations pourraient évaluer systématiquement si une approche d'ingénierie de ligne de produits conviendrait à leur organisation. A cette fin, cette recherche a suivi une méthodologie de *design-science* pour élaborer et évaluer un cadre d'évaluation de la motivation et de la préparation des organisations à l'adoption d'une ligne de produits (ce cadre s'appelle **APPLIES**).

Huit évaluations empiriques ont été menées pour évaluer **APPLIES** en termes de facilité d'utilisation, de pertinence du contenu, d'utilité perçue, d'intention d'utilisation et d'améliorations potentielles. Les évaluations ont été définies à l'aide d'une conception de multi-méthodes complémentaire qui incluait à la fois des points de vue académiques et industriels.

De manière générale, même si le cadre **APPLIES** est loin d'être parfait, son évaluation critique donne des résultats prometteurs: les répondants estiment que **APPLIES** fournit des informations utiles et qu'ils le recommanderaient au public concerné: les personnes intéressées par l'évaluation de l'opportunité d'adopter le PLE. **APPLIES** est également jugé utile pour identifier les conditions actuelles d'une organisation en ce qui concerne l'adoption de lignes de produits: il aide à identifier les facteurs que les organisations devraient améliorer, et fournit des informations sur les éléments à prendre en compte avant d'adopter une PLE. De plus, tous les participants aux évaluations qui ont utilisé **APPLIES** ont été capables d'utiliser l'outil de manière autonome pour évaluer la motivation et la préparation d'une organisation à adopter une PLE.

Enfin, avant de conclure, cette thèse présente des recommandations qui peuvent être utilisées pour améliorer **APPLIES** à l'avenir, suite à l'analyse et à la réflexion du chercheur sur les résultats de l'évaluation, ainsi qu'aux suggestions recueillies auprès des participants aux évaluations.

Mots-clés: adoption d'ingénierie de ligne de produits, prise de décision pour l'adoption de lignes de produits, évaluation empirique.

Chapitre en français - Introduction

Contexte

Ingénierie de ligne de produits

Une ligne de produits est un ensemble de produits similaires qui partagent des caractéristiques communes, répondent aux exigences d'un segment de marché et sont mis en œuvre à partir d'un ensemble commun d'actifs d'une manière prescrite (Clements & Northrop 2001b).

En d'autres termes, créer une ligne de produits signifie créer un portefeuille de produits apparentés de telle sorte qu'il est possible de profiter pleinement des similitudes des produits, tout en respectant et en gérant leurs différences (Clements 2015). Ainsi, au lieu de développer des produits de manière indépendante, les produits d'une ligne de produits sont développés en réutilisant des actifs existants de manière prescrite (Clements & Northrop 2001b).

L'ingénierie de la ligne de produits (PLE) est une approche systématique et complète visant à "concevoir" des lignes de produits de manière efficace, où "concevoir" implique toutes les activités impliquées dans la planification, la production, la livraison, le déploiement, le maintien et le retrait des produits de sorte qu'elles bénéficient des points communs des produits tout en gérant leurs différences (Clements 2015). Dans le cadre de l'approche PLE, la réutilisation est planifiée, activée et appliquée et les produits sont traités comme une entité à part entière et non comme des entités distinctes créées ou maintenues séparément (Clements & Northrop 2001b). Par conséquent, l'adoption d'une approche de PLE n'implique pas seulement l'adoption d'une nouvelle solution technologique mais l'appropriation d'une toute nouvelle façon de faire du business (Clements & Northrop 2001b, Wijnstra 2002, Huysegoms et al. 2011); les organisations doivent acquérir une nouvelle façon de penser pour créer et exploiter une ligne de produits.

D'après les expériences rapportées, les organisations adoptant une approche de PLE pourraient obtenir des avantages tels qu'une productivité améliorée (Clements & Northrop 2001b) et une meilleure qualité des produits (Clements & Northrop 2001b, Pohl et al. 2005). Une productivité améliorée, à son tour, apporte des avantages tels que la réduction du temps de mise sur le marché, la réduction des coûts et/ou l'augmentation du nombre de produits dans le portefeuille de produits (van der Linden et al. 2007, Pohl et al. 2005). En même temps, une augmentation de la qualité des produits peut réduire les coûts et les délais de mise sur le marché, tout en augmentant la satisfaction des clients (Clements & Northrop 2001b, van der Linden et al. 2007, Pohl et al. 2005). En d'autres termes, en utilisant une approche de PLE, les organisations sont potentiellement en capacité de produire des produits flexibles et largement adaptables qui peuvent être livrés en un temps considérablement réduit (Clements & Northrop 2001b, van der Linden et al. 2007, Pohl et al. 2005, Gacek et al. 2001).

Des organisations telles que Volvo (Bilic et al. 2018), Danfoss (Fogdal et al. 2016), General Motors (Young et al. 2017), Renault (Dumitrescu et al. 2013), entre autres, (van der Linden et al. 2007) ont fait état de vastes avantages découlant de l'adoption réussie d'une approche PLE.

Les étapes de l'adoption - le processus d'adoption d'une innovation

Comme il a été présenté dans la section précédente, le PLE est une alternative intéressante pour de nombreuses organisations. Cependant, comme tout changement organisationnel, l'adoption d'une approche de PLE implique des conséquences, des effets secondaires et des exigences minimales dont les adoptants potentiels doivent tenir compte avant de décider de l'adopter ou non. En outre, il est souvent très difficile de faire adopter une nouvelle idée, même si elle présente des avantages évidents. Le processus de décision en matière d'innovation proposé par Rogers (1983) est un processus théorique qui aide les responsables du changement à comprendre ce dont ils doivent tenir compte lorsqu'ils introduisent une innovation dans les organisations. C'est pourquoi la recherche présentée dans cette thèse utilise ce processus comme cadre pour définir comment évaluer la convenance d'adopter une approche de PLE.

Selon Rogers (1983), un processus de décision d'innovation se produit lorsqu'une organisation envisage d'adopter potentiellement une idée, un produit, un service, un objet, une méthode ou, en général, tout ce qui est perçu comme nouveau par l'organisation. Cette perception de nouveauté se produit, par exemple, soit parce que l'organisation n'a aucune connaissance préalable de l'idée, soit parce que l'organisation n'a aucune attitude préalable favorable ou défavorable à son égard.

L'adoption d'une nouvelle idée se fait en deux étapes dans les organisations : *initiation* et *Agenda-setting*. Entre ces deux étapes, une décision d'adoption est prise (voir la figure 1.1). Les étapes sont expliquées plus en détail ci-dessous :

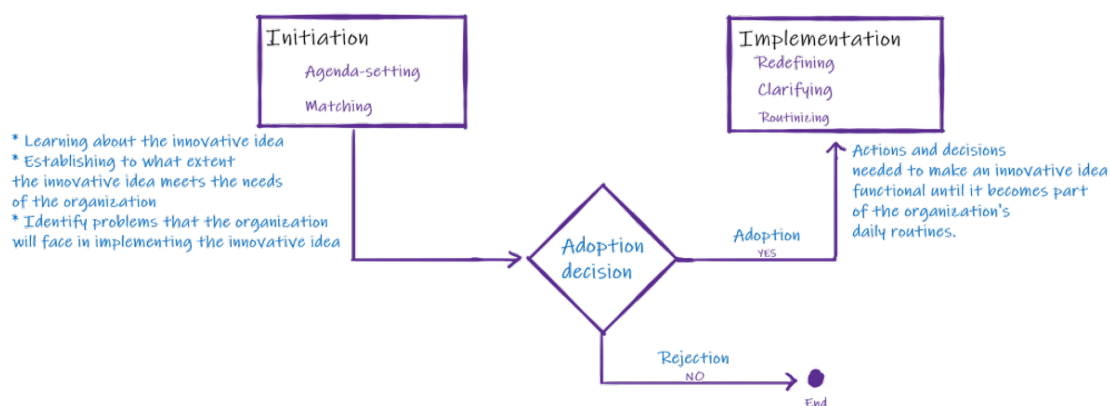


Figure 1: Processus d'adoption d'une innovation. Adapté de Rogers (1983).

- *Initiation*. Au cours de cette étape, les membres des organisations évaluent l'utilité potentielle d'une idée nouvelle. Cette évaluation conduit au développement d'une attitude, positive ou négative, envers l'idée qui se matérialise par la décision d'adopter ou de rejeter l'innovation (Rogers 1983). L'étape d' *initiation* comprend deux activités principales qui conduisent les organisations désireuses de répondre à un besoin (par exemple, réduire la divergence entre leur performance attendue et leur performance réelle) à décider d'adopter ou de rejeter l'idée innovante. Ces activités sont *agenda-setting* et *matching*.

- Agenda-setting*. Il s'agit de la motivation initiale à envisager une idée innovante. Cette motivation peut être initiée par un problème ou par une innovation. Dans le premier scénario, une ou plusieurs personnes d'une organisation identifient un problème important et cherchent ensuite un moyen de le résoudre. Dans le second scénario, une ou plusieurs personnes prennent conscience de l'existence d'une nouvelle idée et découvrent ensuite qu'elles en ont besoin. Dans les deux scénarios, les personnes d'une organisation reconnaissent la nécessité de résoudre un problème (Rogers 1983).

ii *Matching*. This activity is aimed at establishing to what extent an innovative idea meets the organizational needs and to identify the problems that organizations will face once they decide to adopt the innovative idea (Rogers 1983).

- *Adoption decision*. Il s'agit de la décision d'adopter ou de rejeter une idée neuve car elle constitue la meilleure voie d'action possible pour l'organisation (Rogers 1983).
- *Implementation*. Lorsqu'une organisation décide d'adopter une nouvelle idée, l'étape de la mise en œuvre commence. Cette étape comprend les actions et les décisions nécessaires pour rendre l'innovation fonctionnelle jusqu'à ce qu'elle fasse partie des routines quotidiennes de l'organisation. (Rogers 1983).

Problème

Problem statement

Selon le dictionnaire Oxford, une chose est convenable quand elle est utile et peut rendre les choses plus faciles ou plus rapides¹. En ce sens, l'adoption d'une approche de PLE peut être considérée comme "convenable" lorsqu'elle représente le meilleur plan d'action possible pour une organisation.

Décider d'adopter ou de rejeter une approche de PLE exige que les organisations suivent un *processus de décision en matière d'innovation* car elles doivent décider si elles adoptent quelque chose qu'elles n'ont jamais essayé auparavant. L'adoption de la PLE a attiré l'attention de nombreux chercheurs. Par exemple, certains auteurs ont proposé des méthodes pour mener à bien l'adoption de la PLE (Bayer et al. 1999, Böckle et al. 2002, Mansell 2006, Simon & Eisenbarth 2002, Northrop 2004, Kuvaja et al. 2011, Clements et al. 2012). D'autres ont fait état de leurs expériences lors de l'adoption d'une approche de PLE dans des contextes industriels ou universitaires : (Ebert & Smouts 2003, Steger et al. 2004, Kircher et al. 2006, van der Linden et al. 2007, Nazar & Rakotomahefa 2016, Fogdal et al. 2016, Bastos et al. 2017, Bröckers 2018, Fritsch et al. 2020, Abbas et al. 2020, Lindohf et al. 2021). D'autres encore ont organisé les facteurs qui indiquent qu'une organisation est prête à adopter une approche de PLE (Tüzün et al. 2015, Niemelä 2005, Fritsch & Hahn 2004), ont étudié les obstacles à une adoption réussie (Catal 2009, Jha & O'Brien 2009, Bastos et al. 2011, 2017) et évalué les initiatives de PLE en cours (Schmid & John 2002, Northrop et al. 2005, van der Linden et al. 2004, Ahmed & Capretz 2011a,b, 2010, 2005).

Malgré les nombreuses publications relatives à l'adoption de PLE, la plupart des recherches publiées se concentrent sur l'étape de la mise en œuvre du processus de décision en matière d'innovation. Cependant, il existe peu de recherches sur les défis à relever, en particulier pour ceux qui maîtrisent moins la PLE, au cours de l'étape *initiation* du processus de décision, c'est-à-dire l'étape où l'utilité potentielle d'une idée innovante est évaluée, à l'aide de *agenda-setting* et *matching*.

En particulier, les nouveaux venus dans la PLE peuvent avoir une connaissance détaillée de leurs produits et des conditions organisationnelles, mais il est peu probable qu'ils soient des experts en PLE. En dehors des expériences rapportées par d'autres organisations qui ne reflètent pas nécessairement les conditions spécifiques d'une organisation, les nouveaux venus ne seront probablement pas au courant des facteurs clés qu'ils doivent prendre en compte pour justifier leur décision, ni de la manière de mener une évaluation reproductible et bien organisée (Kircher et al. 2006)..

Ce manque d'expertise fait qu'il est difficile pour les nouveaux venus d'évaluer objectivement l'intérêt ou

¹source : Online Oxford Dictionary, disponible à l'adresse suivante : <https://www.oed.com/>

non d'adopter une approche de PLE. L'absence d'un cadre approprié, prêt à l'emploi et facile à comprendre pour toute personne qui n'est pas un expert signifie qu'ils doivent recourir à des pratiques " d'essai et d'erreur ". Ainsi, les nouveaux venus risquent de passer à côté de points importants dans leur évaluation et, de plus, toute évaluation qu'ils effectuent serait difficile à reproduire (Clements & Northrop 2001b). Au moment de prendre une décision, les personnes susceptibles de soutenir ou de rejeter une approche de PLE devraient être en mesure d'utiliser des arguments bien fondés concernant la commodité (ou non) d'une telle adoption (Clements & Northrop 2001b).

Une solution possible à ce problème serait d'engager une équipe de consultants externes qui pourrait guider l'évaluation et fournir une opinion d'expert. Au sein de la communauté PLE, il existe de tels services de conseil qui aident les organisations dans le processus d'adoption (par exemple, BigLever, Pure-systems ou l'Institut Fraunhofer de génie logiciel expérimental et l'Institut de génie logiciel). Cependant, sans une attitude initiale favorable à l'égard de la PLE, il est peu probable que les nouveaux arrivants soient disposés à allouer des ressources financières à des services de conseil.

Objectif et questions de recherche

En référence au problème précédemment exposé dans la section 1.2.1, la question à laquelle répond cette recherche est la suivante : *comment les débutants en ingénierie de ligne de produits pourraient-ils évaluer plus facilement si l'ingénierie de ligne de produits convient, ou non, à leur organisation ?*

Cette question principale est décomposée en deux questions de recherche :

RQ1 *Quels sont les facteurs que les débutants en PLE doivent prendre en compte afin d'évaluer la motivation et la préparation d'une organisation à adopter une approche de PLE?*

Rationale. Au cours de la étape d'initiation, de multiples facteurs peuvent contribuer au développement d'attitudes positives ou négatives envers l'adoption d'une approche de PLE. Cette recherche part du principe que le terme " convenance " peut être décomposé en deux concepts : **motivation** et **préparation**, sur la base des activités (*agenda-setting* et *matching*) mentionnées dans l'étape *initiation* du processus d'adoption d'une innovation. Il a été démontré que ces deux construits influencent l'efficacité des organisations dans leur intention d'adopter des innovations technologiques (Damanpour & Daniel Wischnevsky 2006, Rafferty et al. 2013). À titre d'illustration, Armenakis et al. (1993) cité dans Rafferty et al. (2013) proposent deux composantes clés pour parvenir à la préparation au changement : (i) la conviction que le changement est nécessaire, ce qui signifie qu'il y a une motivation pour effectuer le changement ; et (ii) la conviction que l'individu et l'organisation ont la capacité de réaliser le changement, ce qui signifie qu'ils sont préparés à le faire. Cette question vise donc à identifier et à organiser les facteurs de décision qui peuvent être utilisés pour évaluer la motivation et la préparation d'une organisation. Cette évaluation, à son tour, peut encourager ou empêcher la décision d'adopter une approche de PLE.

RQ2 *Comment ces facteurs identifiés peuvent-ils être organisés et opérationnalisés dans un cadre qui aide les débutants en PLE à réaliser l'évaluation*

Rationale. "Opérationnaliser", dans le contexte de cette question de recherche, signifie définir comment les informations relatives aux facteurs identifiés seront collectées, mesurées, interprétées et présentées. Cette question vise donc à définir les formats de réponse pour collecter les données d'entrée, les indicateurs de performance pour calculer les résultats, les produits pour résumer les résultats et le processus que les débutants devraient suivre pour effectuer l'évaluation.

Pour répondre à ces questions, cette recherche part du principe qu'un cadre d'évaluation organisé pourrait aider les nouveaux arrivants à comprendre pourquoi l'ingénierie des lignes de produits est, ou n'est pas, pratique

pour leur organisation. Cette hypothèse est justifiée parce que les organisations suivent une activité de recherche et de traitement de l'information pour passer de la prise de conscience d'une idée innovante à l'adoption ou au rejet d'une innovation (Rogers 1983). En d'autres termes, les adoptants potentiels vont essayer d'obtenir des informations pour réduire l'incertitude ou les conséquences indésirables. Un cadre d'évaluation organisé pourrait donc les aider à recueillir les données qui faciliteront le processus de prise de décision. Ainsi, cette dissertation a l'objectif suivant :

Concevoir et évaluer un cadre qui aidera les débutants dans l'ingénierie des lignes de produits à évaluer les raisons pour lesquelles l'ingénierie des lignes de produits convient ou non à leur organisation

Avec cet objectif en perspective, cette recherche vise à produire:

(i) Un cadre d'évaluation qui aidera ceux qui envisagent d'adopter une approche d'ingénierie de ligne de produits à obtenir des informations, afin de réduire l'incertitude de leur décision.

(ii) Une évaluation empirique solide du cadre proposé. Cette évaluation inclut différentes parties prenantes et différents contextes afin d'obtenir des informations qui peuvent être utilisées pour affiner la couverture, le contenu et la conception du cadre proposé.

Justification

Depuis 2008, les chercheurs du *Centre de Recherche en Informatique (CRI)* de l'Université Paris 1 s'intéressent aux problématiques liées à l'ingénierie des lignes de produits. En décembre 2021, au moins huit thèses de doctorat ont été présentées sur des sujets liés à l'ingénierie des lignes de produits. La recherche présentée dans cette thèse vise à contribuer à l'ensemble des connaissances sur l'ingénierie des lignes de produits, en cohérence avec les autres efforts réalisés depuis cet institut de recherche. En particulier, cette section expose trois raisons qui justifient cette recherche:

Une approche de PLE n'est pas une solution idéale pour tous les cas. L'adoption d'une approche de PLE est une alternative qui vise à réduire les coûts et les efforts et à augmenter la productivité de l'entreprise (Clements & Northrop 2001b). Cependant, la PLE n'est pas une "solution miracle" qui peut être appliquée à toutes les organisations en toutes circonstances (Tischer et al. 2007, Bröckers 2018). Les chercheurs ont constaté que l'adoption d'une approche d'ingénierie de ligne de produits implique de surmonter des obstacles que toutes les organisations ne sont pas prêtes à affronter (Bastos et al. 2011, Azanza et al. 2021). Certains de ces obstacles sont, par exemple, le temps qui doit être investi dans le processus d'adoption, les coûts liés à l'établissement de la ligne de produits, la nécessité de mettre en œuvre de nouvelles pratiques, de nouveaux processus ou de nouvelles formations dans l'organisation, et de surmonter la résistance culturelle normale au changement (Catal 2009, Jabar et al. 2013, Bastos et al. 2011, Azanza et al. 2021). En fait, une organisation qui ne connaît pas les facteurs indispensables à l'adoption d'une ligne de produits a peu de chances de réussir de manière rentable et en temps voulu (Northrop 2004). .

Subjectivité. Les résultats d'un processus décisionnel dépendent des connaissances, de l'expérience, des compétences, des attitudes subjectives et des valeurs des décideurs (Pohanková 2010). Cependant, toutes les innovations comportent un certain degré d'incertitude pour les individus, qui seront généralement incertains des résultats de la nouvelle idée. Même si une certaine subjectivité est inévitable dans la prise de décision (Strigini 1996), une approche systématique qui aide les nouveaux venus à évaluer l'opportunité d'entreprendre une initiative de PLE fournirait aux responsables des informations clés qui pourraient réduire l'incertitude de leur décision.

Il est plus économique et plus efficace d'évaluer la convenance d'adopter la PLE à l'avance, plutôt que de rater dans une tentative de mise en œuvre. Le coût de l'évaluation de la convenance de l'adoption d'une approche d'ingénierie de ligne de produits est négligeable par rapport au coût que représente un échec de l'adoption, et pas seulement en termes monétaires. Par exemple, un démarrage raté pourrait miner la confiance des membres de l'organisation, accroître la résistance de l'équipe aux futures initiatives de changement et mettre en danger la crédibilité des dirigeants (Clements et al. 2006, Smith & Sidky 2009). MDe plus, une fois que les organisations ont adopté une approche de PLE, si la mise en œuvre de cette initiative ne fonctionne pas, il serait coûteux les organisations de revenir à une approche traditionnelle. Elles devraient ajuster non seulement la façon dont elles produisent leurs produits, mais également leur structure organisationnelle, leurs finances et leurs plans d'organisation (Clements et al. 2006).

Hypothèses

Cette recherche se base sur les hypothèses suivantes:

- La décision d'adopter une approche de PLE est une décision d'autorité en matière d'innovation (Rogers 1983). Le choix d'adopter ou de rejeter une initiative de PLE est fait par un nombre relativement limité de personnes dans une organisation ou une unité de business. Ces personnes possèdent du pouvoir, un statut ou une expertise technique et ce sont elles qu'il faut convaincre de la convenance ou non d'adopter la PLE.
- Une stratégie d'auto-évaluation est la plus appropriée pour l'étape d'*initiation* d'un processus de décision en matière d'innovation, car il est peu probable que les organisations investissent des ressources pendant l'évaluation parce que l'utilité d'une initiative de ligne de produits est encore incertaine.

Scope

La portée de cette recherche est limitée de la manière suivante:

- Aider les débutants en matière de PLE à évaluer la convenance d'adopter une approche de PLE, mais toute activité ultérieure telle que la planification, la mise en œuvre ou l'évaluation de l'adoption dépasse le cadre de cette étude. Une recherche future pourrait utilement prolonger cette étude en se concentrant sur l'articulation de ce qui existe déjà en matière d'adoption de PLE.
- La portée de cette recherche exclut également la recommandation d'alternatives autres que l'adoption d'une approche de PLE. L'objectif est d'évaluer la convenance de l'adoption de la PLE et non pas de comparer la PLE à d'autres solutions.

Contributions

En plus de fournir des orientations pour les travaux futurs, cette étude apporte quatre contributions majeures à l'industrie et à la communauté académique intéressées par l'ingénierie des lignes de produits, et une contribution supplémentaire à la communauté académique en général.

- i Du point de vue de l'industrie, **APPLIES** atteint l'objectif de cette thèse : il fournit aux débutants en PLE un mécanisme organisé et pratique qui les aide à comprendre la motivation et la préparation d'une organisation à adopter une approche d'ingénierie de la ligne de produits. Bien qu'il soit loin d'être parfait, ce cadre offre une solution prête à l'emploi qui permet aux débutants d'évaluer de façon autonome l'opportunité d'adopter une approche de PLE dans leur organisation.

-
- ii Comme il a été mentionné précédemment, le cadre **APPLIES** est loin d'être complet, mais les évaluations empiriques réalisées fournissent des indications cruciales sur la manière d'améliorer le cadre, notamment en soulignant les éléments qui devraient être maintenus, améliorés ou abandonnés aux niveaux conceptuel, opérationnel et de mise en œuvre du cadre. Ainsi, le travail décrit dans cette thèse sert de point de départ à une nouvelle itération du cadre et à une évolution sur la voie d'une solution plus mature et plus complète.
- iii D'un point de vue académique, cette thèse identifie une brèche dans la littérature existante sur l'ingénierie des lignes de produits : la majorité des études se concentrent sur la mise en œuvre de la PLE mais il existe peu d'informations pour aider les responsables à décider si une approche de PLE serait pertinente pour leur organisation, à moins qu'ils n'engagent des experts pour effectuer une analyse. Sachant que la communauté de l'ingénierie des lignes de produits recherche activement de nouvelles solutions qui font le lien entre l'ingénierie des lignes de produits et la pratique industrielle, il est essentiel d'élargir cet intérêt pour soutenir les organisations qui en sont aux premières étapes de leur processus décisionnel et simplifier le parcours des débutants.
- iv Dans la lignée du point précédent, cette recherche contribue à sensibiliser la communauté des lignes de produits à la nécessité de guider et d'aider à la prise de décision les nouveaux venus au point de départ de leur processus de décision en matière d'innovation. Dans le cadre de ce processus de sensibilisation et de diffusion, au cours de la phase d'évaluation, **APPLIES** a été présenté à des personnes de l'industrie ayant une expérience en ingénierie logicielle, ainsi qu'à des experts universitaires et industriels des lignes de produits. **APPLIES** a également été présenté, en tant qu'exposé invité, lors du 6e atelier international sur l'ingénierie de la variabilité inverse, REVE, qui s'est tenu conjointement avec la 22e conférence internationale des lignes de produits logiciels². En outre, toutes les publications ont été regroupées dans un projet Research Gate³ qui met les travaux à la disposition des pairs de la communauté scientifique. Jusqu'en décembre 2021, l'ensemble du projet a reçu plus de 171 lectures.

En complément, un site web présentant le projet est disponible pour une consultation libre par la communauté⁴. Depuis ce site, les gens peuvent accéder à l'outil qui supporte la dernière version du cadre. Jusqu'en décembre 2021, l'outil a été téléchargé 203 fois et le site web a reçu des visites de personnes en Colombie, aux États-Unis, en France, au Mexique, en Italie, en Suède, en Espagne, en Finlande et en Allemagne.

Contribuant également à la diffusion du projet, des contributions académiques ont été soumises à diverses instances scientifiques, et validées par une évaluation par les pairs. Voici la liste des articles acceptés.

- **Best paper award Luisa Rincon**, Raul Mazo, and Camille Salinesi. 2018. APPLIES: A framework for evaluating organization's motivation and preparation for adopting product lines. In Proceedings of the 12th International Conference on Research Challenges in Information Science (RCIS), 1–12. DOI:10.1109/RCIS.2018.8406641.
- **Luisa Rincon**, Raul Mazo, and Camille Salinesi. 2018. Evaluating Company's Readiness for Adopting Product Line Engineering: a Second Evaluation Round. *Complex Syst. Informatics Model. Q.* 17, 17 (December 2018), 69–94. DOI:10.7250/csimq.2018–17.04

²Cet atelier a eu lieu le 10 septembre 2018.

³<https://www.researchgate.net/project/APPLIES-framework-for-evaluating-organizations-motivation-and-Preparedness-for-adopting-product-LInES>

⁴www.applies.variamos.com

- **Luisa Rincon**, Jaime Chavarriaga, Raul Mazo, and Camille Salinesi. 2018. How Useful and Understandable is the **APPLIES** Framework? a Preliminary Evaluation With Software Practitioners. In Proceedings of the ICAI Workshops (ICAIW), 1–6. DOI:10.1109/ICAIW.2018.8555002
- **Luisa Rincon**, Raul Mazo, and Camille Salinesi. 2019. Analyzing the Convenience of Adopting a Product Line Engineering Approach: an industrial qualitative evaluation. In: Proceedings of the 23rd International Systems and Software Product Line Conference Volume B (SPLC19). New York, New York, USA: ACM Press; 2019:1-8. DOI:10.1145/3307630.3342418
- **Luisa Rincon**, Raul Mazo, and Camille Salinesi. 2020. A multi-company empirical evaluation of a framework that evaluates the convenience of adopting product line engineering. In: Proceedings of the 24th ACM International Systems and Software Product Line Conference - Volume B(SPLC20) pp. 13–20. DOI:10.1145/3382026.3425774

v Enfin, il y a un autre résultat inattendu à souligner. La transcription des enregistrements étant une activité importante pour l’analyse des données collectées dans cette recherche, un guide pour la transcription des enregistrements audio a été élaboré et publié en Research Gate⁵. En décembre 2021, ce guide a été consulté par plus de 10737 personnes provenant de différents domaines de connaissances. Ainsi, au moins un produit réalisé dans le cadre de cette recherche a apporté une contribution aux chercheurs d’autres disciplines.

Organisation de la thèse

- **Chapitre 2: Etat de l’art.** Ce chapitre présente une vue d’ensemble des approches proposées dans la littérature relative aux processus de prendre des décisions pour adopter une approche d’ingénierie de ligne de produit, ainsi que l’identification des lacunes possibles dans la littérature actuelle.
- **Chapitre 3: Conception de la recherche .** Ce chapitre présente la méthodologie de recherche et une description de la manière dont le plan de recherche a été exécuté. De plus, les menaces potentielles à la validité de la recherche sont identifiées et discutées.
- **Chapitre 4: Le cadre APPLIES.** Ce chapitre présente **APPLIES**, le cadre d’évaluation conçu pour aider les organisations à évaluer la convenance d’adopter une approche d’ingénierie de ligne de produits. En particulier, ce chapitre détaille les principales caractéristiques du cadre proposé.
- **Chapitre 5: Résultats de l’évaluation des APPLIES.** Ce chapitre rassemble et analyse les données recueillies lors de huit évaluations empiriques. Il présente les résultats de l’évaluation d’**APPLIES** en termes de facilité d’utilisation, de pertinence du contenu, d’utilité perçue et d’intention d’utilisation.
- **Chapitre 6: Vers une version évoluée - recommandations.** Ce chapitre présente des recommandations à prendre en compte pour la conception et la fonctionnalité d’une version ultérieure de **APPLIES**.
- **Chapitre 7: Conclusion et perspectives.** Ce chapitre résume les principaux éléments de cette thèse, répond aux questions de recherche, présente les leçons apprises et les limites de l’étude. Enfin, ce chapitre propose des domaines de recherche futurs potentiels qui pourraient aborder les brèches dans les connaissances et les pratiques actuelles.

⁵https://www.researchgate.net/publication/333059442_Guide_for_transcribing_audio_records

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CHAPTER 1

Introduction

1.1 Context

1.1.1 Product Line Engineering

A product line is a set of similar products that share common characteristics, meet the requirements of a market segment and are implemented from a common set of assets in a prescribed way (Clements & Northrop 2001b). In other words, creating a product line means creating a portfolio of related products in such way that it is possible to take full advantage of the products' similarities, while respecting and managing their differences (Clements 2015). Thus, instead of developing products independently, the products of a product line are developed by reusing existing assets in a prescribed way (Clements & Northrop 2001b).

Product Line Engineering (PLE) is a systematic and comprehensive approach aimed at “engineering” product lines in an efficient manner, where “engineering” implies all of the activities involved in planning, producing, delivering, deploying, sustaining, and retiring products in such a way that they take advantage of products' commonalities while controlling their differences (Clements 2015). Under the PLE approach reuse is planned, enabled and enforced and products are treated as a whole entity and not as separate entities that are created or maintained separately (Clements & Northrop 2001b). Therefore, adopting a PLE approach implies not just adopting a new technological solution but appropriating an entirely new way of doing business (Clements & Northrop 2001b, Wijnstra 2002, Huysegoms et al. 2011); organizations need to acquire a new way of thinking for creating and operating a product line.

Based on reported experiences, organizations adopting a PLE approach could achieve benefits such as increased productivity (Clements & Northrop 2001b) and increased product quality (Clements & Northrop 2001b, Pohl et al. 2005). Increased productivity, in turn, brings benefits such as reduced time to market, reduced costs, and/or an increase in the number of products in the product portfolio (van der Linden et al. 2007, Pohl et al. 2005). At the same time, an increase in product quality can reduce costs and time to market, as well as increasing customer satisfaction (Clements & Northrop 2001b, van der Linden et al. 2007, Pohl et al. 2005). That is to say, by using a PLE approach organizations are potentially able to produce flexible and widely tailorable products which are deliverable in a greatly reduced amount of time (Clements & Northrop 2001b, van der Linden et al. 2007, Pohl et al. 2005, Gacek et al. 2001).

Organizations such as Volvo (Bilic et al. 2018), Danfoss (Fogdal et al. 2016), General Motors (Young et al. 2017), Renault (Dumitrescu et al. 2013), among others, (van der Linden et al. 2007) have reported wide-ranging benefits from the successful adoption of a PLE approach.

1.1.2 Adoption stages - the innovation decision process

As presented in the previous section, PLE is an attractive alternative for many organizations. However, as any organizational change, adopting a PLE approach implies consequences, side effects, and minimal requirements that the potential adopters should consider before deciding whether to adopt or reject it. In addition, it is often very difficult to get a new idea adopted, even if it has obvious advantages. The innovation decision process proposed by Rogers (1983) is a theoretical process that helps change leaders to understand what they need to consider when introducing innovation in organizations. For this reason, the research presented in this thesis uses this process as a framework to define how to evaluate the convenience of adopting a PLE approach.

According to Rogers (1983) an innovation decision process occurs when an organization considers potentially adopting an idea, product, service, object, method, or in general, anything that is perceived as new by the organization. This perception of novelty occurs, for example, either because the organization has no prior knowledge about the idea or because the organization has no prior favorable or unfavorable attitude about it.

There are two stages in which the adoption of a new idea occurs in organizations: *initiation* and *implementation*. Between the two stages an adoption decision is made (see Figure 1.1). The stages are explained in more detail below:

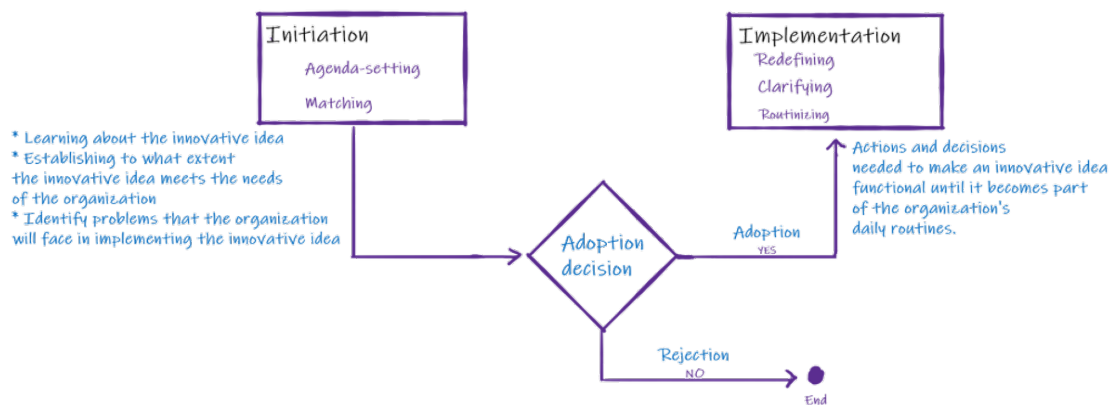


Figure 1.1: Innovation decision process. Adapted from Rogers (1983).

- *Initiation*. During this stage people in organizations evaluate the potential usefulness of an innovative idea. This evaluation leads to developing an attitude, positive or negative, towards the idea that results in the decision to adopt or reject the innovation (Rogers 1983). The *initiation evaluation* comprises two principal activities that lead organizations interested in addressing a need (e.g., reducing the gap between their expected and actual performance) to decide whether to adopt or reject the innovative idea. These activities are *agenda-setting* and *matching*.
 - i *Agenda-setting*. This is related to the initial motivation for considering an innovative idea. This motivation can be either problem-initiated or innovation-initiated. In the first scenario, one or more individuals in an organization identify an important problem and then seek a means for solving it. In the second scenario, one or more individuals become aware that a new idea exists and then discover that they have a need for it. In both scenarios, people in an organization recognize the need to solve a problem (Rogers 1983).
 - ii *Matching*. This activity is aimed at establishing to what extent an innovative idea meets the organizational needs and to identify the problems that organizations will face once they decide to adopt the innovative idea (Rogers 1983).

- *Adoption decision.* This is the decision to adopt or reject the innovative idea as the best course of action available for the organization (Rogers 1983).
- *Implementation.* In the event that an organization decides to adopt an innovative idea, the *implementation* stage begins. This stage includes the actions and decisions needed to make the innovation functional until it becomes part of the organization's daily routines (Rogers 1983).

1.2 Problem

1.2.1 Problem statement

According to the Oxford Dictionary, something is convenient when it is useful and can make things easier or quicker¹. In this sense, adopting a PLE approach could be considered “convenient” when that adoption represents the best possible course of action for an organization.

Deciding to adopt or reject a PLE approach requires that organizations undergo an *innovation decision process* as they need to decide whether to adopt something that they have never tried before. The adoption of PLE has attracted the attention of numerous researchers. For example, some authors have proposed methods for carrying out the adoption of PLE (Bayer et al. 1999, Böckle et al. 2002, Mansell 2006, Simon & Eisenbarth 2002, Northrop 2004, Kuvaja et al. 2011, Clements et al. 2012). Others have reported on experiences while adopting a PLE approach in industrial or academic contexts (Ebert & Smouts 2003, Steger et al. 2004, Kircher et al. 2006, van der Linden et al. 2007, Nazar & Rakotomahefa 2016, Fogdal et al. 2016, Bastos et al. 2017, Bröckers 2018, Fritsch et al. 2020, Abbas et al. 2020, Lindohf et al. 2021). Still others have organized factors that denote an organization's preparedness to adopt a PLE approach (Tüzün et al. 2015, Niemelä 2005, Fritsch & Hahn 2004), investigated barriers to successful adoption (Catal 2009, Jha & O'Brien 2009, Bastos et al. 2011, 2017) and evaluated ongoing PLE initiatives (Schmid & John 2002, Northrop et al. 2005, van der Linden et al. 2004, Ahmed & Capretz 2011a,b, 2010, 2005).

Despite the numerous publications related to the adoption of PLE, most of the published research focuses on the *implementation* stage of the innovation decision process. However, there is little research into the challenges that are faced, particularly for those who are less proficient in PLE, during the *initiation* stage of the decision-making process, i.e., the stage where the potential usefulness of an innovative idea is evaluated, using *agenda-setting* and *matching*.

In particular, newcomers to PLE might have detailed knowledge about their products and organizational conditions, but it is unlikely that they will be experts in PLE. Apart from experiences reported by other organizations which do not necessarily reflect an organization's specific conditions, newcomers will probably be unaware of key factors they need to consider to justify their decision, as well as how to conduct a replicable and well-organized evaluation (Kircher et al. 2006).

This lack of expertise makes it difficult for newcomers to objectively evaluate the convenience or otherwise of adopting a PLE approach. The lack of a suitable ready-to-use framework that is easy to grasp by anyone less than an expert means that they have to use ‘trial and error’ practices. Thus, newcomers risk missing important points in their evaluation and, additionally, any evaluation they conduct would be difficult to replicate (Clements & Northrop 2001b). When making a decision, individuals who might support or reject a PLE approach should be able to use well-founded arguments regarding the convenience (or not) of such an adoption (Clements &

¹source: Online Oxford Dictionary, available at: <https://www.oed.com/>

Northrop 2001b).

One possible solution to this problem would be to hire an external consulting team who could guide the evaluation and provide expert opinion. Within the PLE community there are such consultancy services that assist organizations in the adoption process (e.g., BigLever, Pure-systems or Fraunhofer Institute of Experimental Software Engineering and the Software Engineering Institute). However, without an initial favorable attitude towards PLE it is unlikely that newcomers would be willing to allocate financial resources to consultancy services.

1.2.2 Research goal and research questions

With reference to the problem previously outlined in Section 1.2.1, the question that this research addresses is *how could newcomers to product line engineering more easily evaluate whether product line engineering is, or is not, convenient for their organization?*

This main question is broken down into the following two research questions:

RQ1 *What factors do newcomers to PLE need to consider in order to evaluate an organization's motivation and preparedness for adopting a PLE approach?*

Rationale. During the *initiation stage* multiple factors may contribute to the development of positive or negative attitudes towards adopting a PLE approach. This research assumes that the term “convenience” can be broken down into two constructs: **motivation** and **preparedness**, based on the activities (*agenda-setting* and *matching*) mentioned in the *initiation* stage of the innovation decision process. These two constructs have been shown to influence the effectiveness of organizations in their intention to adopt technological innovations (Damanpour & Daniel Wischnevsky 2006, Rafferty et al. 2013). As illustration of this, Armenakis et al. (1993) cited in Rafferty et al. (2013) propose two key components to achieve change readiness: (i) the belief that the change is needed, which means that there is motivation to carry out the change; and (ii) the belief that the individual and the organization have the capacity to undertake the change, which means that they are prepared to do it. This question aims, therefore, to identify and organize decision-making factors that can be used to evaluate an organization's motivation and preparedness. This evaluation, in turn, may either encourage or impede a decision to adopt a PLE approach.

RQ2 *How can these identified factors be organized and operationalized into a framework that assists newcomers to PLE to implement the evaluation?*

Rationale. “Operationalize”, in the context of this research question, means to define how information relating to the identified factors will be collected, measured, interpreted and presented. This question, therefore, aims to define the response formats to collect input data, the performance indicators to calculate the results, the outputs to summarize the results and the process newcomers would need to follow to carry out the evaluation.

To answer these questions, this research assumes that an organized evaluation framework could assist newcomers² in understanding to what extent and why product line engineering is, or is not convenient³ for their organization. This hypothesis is justified because organizations follow an information-seeking and information-processing activity to pass from awareness of an innovative idea to the adoption/rejection of an innovation (Rogers 1983). In other words, potential adopters will try to obtain information to reduce uncertainty or undesired consequences. An organized evaluation framework, therefore, could help them to gather the data that

²According to Oxford Dictionary: newcomer - A person who has only recently arrived in a place or started an activity.

³According to Oxford Dictionary: convenient - A quality of being easy, useful, or suitable to proceed with something without difficulty (Oxford Dictionary).

will assist with the decision-making process. Thus, this dissertation has the following objective:

To design and evaluate a framework that will assist newcomers to product line engineering to evaluate to what extent and why product line engineering is, or is not, convenient for their organization.

With this goal in mind, this research aims to provide:

(i) An evaluation framework that will assist those considering adopting a product line engineering approach to obtain information, in order to reduce the uncertainty of their decision.

(ii) A robust empirical evaluation of the proposed framework. This evaluation includes different stakeholders and contexts in order to obtain information that can be used to further refine the scope, content and design of the proposed framework.

1.2.3 Justification

Since 2008, researchers at the *Centre de Recherche en Informatique (CRI)* of Paris 1 University have been interested in areas related to product line engineering. As of December 2021, at least eight doctoral theses have been presented on topics relating to product line engineering. The research presented in this dissertation aims to contribute to the body of knowledge on product line engineering, in line with the other efforts made from this research institute. In particular, this section outlines three reasons that justify this research:

A PLE approach is not a silver bullet for every case. Adopting a PLE approach is an alternative that aims to reduce costs and effort and to increase business productivity (Clements & Northrop 2001b). However, PLE is not a “silver bullet” which can be applied to every organization under every circumstance (Tischer et al. 2007, Bröckers 2018). Researchers have identified that adopting a product line engineering approach entails overcoming barriers that not all organizations are prepared to face (Bastos et al. 2011, Azanza et al. 2021). Some of these barriers are, for example, the time that must be invested in the adoption process, the costs involved in establishing the product line, the need to implement new practices, processes or training in the organization, and to overcome normal cultural resistance to change (Catal 2009, Jabar et al. 2013, Bastos et al. 2011, Azanza et al. 2021). In fact, an organization that does not know what factors are indispensable when adopting a product line has little chance of succeeding in a profitable and timely manner (Northrop 2004).

Subjectivity. The outcomes of a decision-making process depend on the knowledge, experience, skills, subjective attitudes and values of the decision-makers (Pohanková 2010). However, all innovations carry some degree of uncertainty for individuals, who will be typically unsure of the new idea’s results. Even if some subjectivity is unavoidable in decision-making (Strigini 1996), a systematic approach that aids newcomers in evaluating the convenience of undertaking a PLE initiative would provide managers with key information that could reduce the uncertainty of their decision.

It is cheaper and more efficient to evaluate the convenience of adopting PLE beforehand, rather than to fail in an implementation attempt. The cost of evaluating the convenience of adopting a product line engineering approach is negligible compared to the cost of an adoption failure, and not just in monetary terms. For example, a failed start could undermine the trust of the organization’s members, increase team resistance to future change initiatives and jeopardize management’s credibility (Clements et al. 2006, Smith & Sidky 2009). Moreover, once organizations have adopted a PLE approach, if the implementation fails, it would be expensive for them to return to a traditional approach. They would have to adjust not only the way they produce their products, but also their organizational structure, finances and organizational plans (Clements et al. 2006).

1.3 Assumptions

This research uses the following assumptions:

- Deciding to adopt a PLE approach is an authority innovation decision (Rogers 1983). The choice to adopt or reject a PLE initiative is made by relatively few individuals in an organization or business unit. Those individuals possess power, status, or technical expertise and are the ones that need to be convinced regarding the convenience or otherwise of adopting PLE.
- A self-evaluation strategy is the most appropriate for the *initiation* purposes of an innovation decision process, as organizations are unlikely to invest resources while conducting the evaluation because the convenience of a product line initiative is still uncertain.

1.4 Scope

The scope of this research is limited as follows:

- To assist newcomers to PLE in evaluating the convenience of adopting a PLE approach, but any subsequent activities such as adoption planning, implementation or evaluation are beyond the scope of this study. Future research could usefully extend this study by focusing on articulating what already exists with regard to PLE adoption.
- The scope of this research also excludes recommending alternatives other than adopting a PLE approach. The purpose is to evaluate the convenience of adopting PLE itself and not to compare PLE to other solutions.

1.5 Contributions

In addition to the provision of some directions for future work, this study makes four major contributions to both the PLE industry and PLE academia, and an additional contribution to the academic community as a whole.

- i From an industry perspective, **APPLIES** achieves what this dissertation set out to do: it provides newcomers to PLE with an organized, practical mechanism that helps them to understand an organization's motivation and preparedness for adopting a product line engineering approach. While far from perfect, the framework offers a ready-to-use solution that makes it easier for newcomers to autonomously evaluate the convenience of adopting a PLE approach in their organizations.
- ii As already mentioned, the **APPLIES** framework is by no means complete but the empirical evaluations carried out provide crucial insights into how to improve the framework, including outlining elements that should be maintained, improved, or discarded at the framework's conceptual, operational and implementation levels. Thus, the work described in this dissertation serves as a starting point for a new iteration of the framework and evolution along the path towards a more mature and complete solution.
- iii From an academic perspective, this dissertation identifies a gap in the existing literature on product line engineering: that the majority of studies focus on the implementation of PLE but there is little information to help decision-makers decide whether a PLE approach would be useful for their organization, unless they hire experts to carry out an analysis. Bearing in mind that the product line engineering community is actively searching for new solutions that bridge product line engineering and industrial practice, it is

essential to broaden this interest to support those organizations in the early stages of their decision-making process and simplify newcomers' paths.

- iv In line with the previous point, this research contributes towards raising awareness within the product line community about the need for guidance and decision-making support for newcomers at the starting point of their innovation-decision process. As part of this process of awareness-raising and dissemination, during the evaluation stage **APPLIES** was presented to individuals from the industry who have experience in software engineering, and to academic and industry experts in product lines. **APPLIES** was also presented, as an invited talk, at the 6th International Workshop on Reverse Variability Engineering, REVE, held in conjunction with the 22nd International Conference of Software Product Lines⁴. Furthermore, all publications were grouped into a Research Gate project⁵ that makes the work available to peers in the scientific community. As of December 2021 the project overall has received more than 171 reads.

In addition, a website presenting the project is available for free consultation by the community⁶. From this website people can access the tool that supports the latest version of the framework. As of December 2021, the tool has had 203 downloads and the website has received visits from people in Colombia, United States, France, Mexico, Italy, Sweden, Finland and Germany.

Also contributing towards the dissemination of the project, academic contributions have been submitted to various scientific venues, and validated through peer review. The following is a list of accepted papers.

- **Best paper award Luisa Rincon**, Raul Mazo, and Camille Salinesi. 2018. APPLIES: A framework for evaluating organization's motivation and preparation for adopting product lines. In Proceedings of the 12th International Conference on Research Challenges in Information Science (RCIS), 1–12. DOI:10.1109/RCIS.2018.8406641.
- **Luisa Rincon**, Raul Mazo, and Camille Salinesi. 2018. Evaluating Company's Readiness for Adopting Product Line Engineering: a Second Evaluation Round. *Complex Syst. Informatics Model. Q.* 17, 17 (December 2018), 69–94. DOI:10.7250/csimq.2018–17.04
- **Luisa Rincon**, Jaime Chavarriaga, Raul Mazo, and Camille Salinesi. 2018. How Useful and Understandable is the **APPLIES** Framework? a Preliminary Evaluation With Software Practitioners. In Proceedings of the ICAI Workshops (ICAIW), 1–6. DOI:10.1109/ICAIW.2018.8555002
- **Luisa Rincon**, Raul Mazo, and Camille Salinesi. 2019. Analyzing the Convenience of Adopting a Product Line Engineering Approach: an industrial qualitative evaluation. In: Proceedings of the 23rd International Systems and Software Product Line Conference Volume B (SPLC19). New York, New York, USA: ACM Press; 2019:1-8. DOI:10.1145/3307630.3342418
- **Luisa Rincon**, Raul Mazo, and Camille Salinesi. 2020. A multi-company empirical evaluation of a framework that evaluates the convenience of adopting product line engineering. In: Proceedings of the 24th ACM International Systems and Software Product Line Conference - Volume B(SPLC20) pp. 13–20. DOI:10.1145/3382026.3425774

⁴This workshop took place on September 10, 2018.

⁵<https://www.researchgate.net/project/APPLIES-framework-for-evaluating-organizations-motivation-and-Preparedness-for-adopting-product-LInES>

⁶www.applies.variamos.com

v Finally, there is one other unexpected result to highlight. Since the transcription of recordings was an important activity for the analysis of the data collected in this research, a guide for transcribing audio recordings was elaborated and published in Research Gate⁷. As of December 2021 this guide has been accessed by more than 10737 people from different backgrounds and from different fields of knowledge, so at least one product produced as part of this research has contributed to researchers of other disciplines.

1.6 Dissertation road-map

- **Chapter 2: State of the art.** This chapter presents an overview of approaches proposed in the literature related to the decision-making processes for adopting a Product Line Engineering approach, as well as identifying possible gaps in the current literature.
- **Chapter 3: Research design.** This chapter presents the research methodology and a description of how the research design was executed. Also, potential threats to the research validity are identified and discussed.
- **Chapter 4: The **APPLIES** framework.** This chapter presents **APPLIES**, the evaluation framework designed to assist organizations in evaluating the convenience of adopting a product line engineering approach. In particular this chapter details the main features of the proposed framework.
- **Chapter 5: Results of the evaluation of **APPLIES**.** This chapter collates and analyzes the data collected from eight empirical evaluations. It presents the results of the evaluation of **APPLIES** in terms of ease of use, content pertinence, perceived usefulness and intention to use.
- **Chapter 6: Towards an evolved version - recommendations.** This chapter presents recommendations to consider for the design and functionality of a subsequent version of **APPLIES**.
- **Chapter 7: Conclusion and perspectives.** This chapter summarizes the overall contributions of this research and proposes potential future areas of research which could address gaps in current knowledge and practice.

⁷https://www.researchgate.net/publication/333059442_Guide_for_transcribing_audio_records

CHAPTER 2

State-of-the-art

Considering the main focus of this research is to assist newcomers in evaluating the convenience of adopting a product line engineering approach, this review of the literature centers around three questions:

- *Q1 - What approaches currently exist that assist newcomers to PLE to evaluate the convenience of adopting a PLE approach or to evaluate ongoing initiatives?*

Rationale. This question seeks to identify existing approaches that address the *initiation* stage of an adoption process, and/or the early stages of an adoption process during the *implementation* stage, and/or the evaluation of ongoing adoption initiatives.

- *Q2 - How do these approaches operationalize an evaluation of the convenience of adopting PLE?*

Rationale. This question aims to: (i) identify the content included in the existing evaluation approaches; (ii) identify how these approaches organize evaluation factors; and (iii) identify the inputs and processes used to carry out the evaluation.

- *Q3 - What gaps exist in current approaches and what challenges will be faced in the future?*

Rational. This question aims to analyze the limitations of existing approaches in order to identify areas for future research on this topic.

This literature review began by looking at seminal papers on PLE adoption such as [Bandinelli & Sagardui \(2000\)](#), [Schmid & John \(2002\)](#), [Bühne et al. \(2004\)](#) and used forward and backward snowballing to encounter related publications. The approaches presented in this chapter were selected because they have a focus on assisting newcomers either during the *initiation* stage of the adoption process, during the early stages of the adoption process, or during the evaluation of an ongoing adoption initiative.

2.1 Q1 - What approaches currently exist that assist newcomers to PLE to evaluate the convenience of adopting a PLE approach or to evaluate ongoing initiatives?

This section organizes the approaches found in the literature according to whether the contribution belongs to the *initiation* stage or to the early stages of *implementation* during the *innovation decision process* (see Section 1.1.2). While the approaches that belong to this latter stage do not necessarily focus on evaluating the convenience of adopting a PLE approach, they do provide complementary information to the topic in hand.

2.1.1 Initiation stage

Despite of the importance of supporting organizations with the right set of tools to evaluate the convenience of adopting a PLE approach, academic research in this specific area of Product Line Engineering is very limited. The literature review conducted in the scope of this research revealed only eight approaches that have addressed how to assist organizations in their decision to whether adopt or not a PLE approach. In particular four approaches aim to evaluate the potential that a domain may have for implementing a product line: [Fritsch & Hahn \(2004\)](#), [Bandinelli & Sagardui \(2000\)](#), [Schmid & John \(2002\)](#), and [Koziolok et al. \(Koziolok et al. 2013, Domis et al. 2014, Koziolok et al. 2016\)](#). In addition, a further four approaches were found that aim to evaluate whether the necessary conditions exist to adopt a PLE approach in organizations: *Product Line Technical Probe - PLTP* ([Northrop et al. 2005](#)), *onePLE solution* ([BigLever Software 2018](#)), the *reuse-invest* and *reuse-check* ([Mansell 2006](#)), and *TransitPL* ([Tüzün et al. 2015](#)). A description of the approaches of both categories are presented below.

Approaches that evaluate the domain of interest

Four separate approaches look at evaluating domain potential: [Fritsch & Hahn \(2004\)](#), [Bandinelli & Sagardui \(2000\)](#), [Schmid & John \(2002\)](#), and [Koziolok et al. \(Koziolok et al. 2013, Domis et al. 2014, Koziolok et al. 2016\)](#). This section provides a brief overview of these approaches, while [Section 2.2](#) presents more detail on the operationalization provided by each analyzed approach.

A domain is “*an area of business/technology processes or knowledge, which is characterized by a set of concepts and terminology understood by stakeholders in that area*” ([Clements & Northrop 2001b](#)). A domain potential analysis evaluates to what extent favourable conditions exist within a domain for product line purposes.

The first approach, the Product Line Potential analysis method, was proposed by [Fritsch & Hahn \(2004\)](#) to evaluate domain potential. This method evaluates whether a systematic product line development would be helpful for an organization according to its target market and potential products. The second approach by [Bandinelli & Sagardui \(2000\)](#) presented a conceptual framework to evaluate domain potential through the identification of risks, benefits and economic impacts. Thirdly, [Schmid & John \(2002\)](#) advanced PuLSE-eco, as part of the PuLSE methodology ([Bayer et al. 1999](#)), which is useful for analyzing benefits in terms of reuse potential and expected risks of the most promising domains of the product line. Finally, the Swiss-Swedish multinational corporation ABB¹ created a proprietary method to evaluate domain potential when an organization already has products to migrate towards a product line ([Koziolok et al. 2013, Domis et al. 2014, Koziolok et al. 2016](#)). The domain analysis method from ABB evaluates to what extent different sets of independent products have the potential to be structured as a product line by (i) considering technical aspects such as feature modeling, software architecture reconstruction and mining of candidate assets; (ii) including economic metrics to estimate cost-avoidance and; (iii) evaluating reuse potential.

Approaches that evaluate preconditions

Four main approaches were identified that focus on evaluating whether necessary conditions exist in order to adopt a PLE approach in organizations: *Product Line Technical Probe - PLTP* ([Northrop et al. 2005](#)), *onePLE solution* ([BigLever Software 2018](#)), the *reuse-invest* and *reuse-check* system from Tecniaia, and *TransitPL* ([Tüzün et al. 2015](#)). The intended population of these approaches are software and system organizations that are already seriously considering a product line initiative and want to evaluate their preparedness for starting it. Each of these approaches is described in more detail below.

First, the Software Engineering Institute - SEI created the *Product Line Technical Probe - PLTP* method

¹www.new.abb.com

(Clements & Northrop 2001a, Northrop et al. 2005). The PLTP method is a diagnostic tool useful for evaluating an organization's preparedness for adopting PLE or for identifying problems when organizations are already running a PLE initiative (Clements & Northrop 2001a). This method consists of a series of semi-structured interviews conducted by a team of consultants who analyze the results and identify the organization's strengths and weaknesses in relation to the product line effort. In addition, the consultants provide recommendations regarding the results obtained.

Second, BigLever² created the *onePLE solution* a holistic solution that guides organizations towards achieving fully-operational PLE capability (BigLever Software 2018). It relies on feature-based development in which variability is represented by features and variation points and products are derived automatically from a configurator named Gears. The OnePLE solution includes two motivational workshops that help organizations to identify the advantages of adopting a PLE approach. Additionally, this solution includes training of managers, technical leaders, practitioners as well as expert mentoring to assist organizations with designing, creating, transitioning, and operating the product line.

Third, Tecnia³ uses Bandinelli & Sagardui (2000)'s approach to put forward its own evaluation methods: the *reuse-invest* and *reuse-check* method. *Reuse-invest* helps to evaluate if it is economically profitable to adopt systematic reuse, while *reuse-check* analyzes the software reuse practices already deployed in a specific domain of the organization as the first step for adopting systematic reuse practices. Tecnia's method operationalizes the categories proposed by Bardinelli et al. through the use of specific factors and attributes. However, details of the *reuse-invest* and *reuse-check* methods are not available to the general public, with the exception of the information reported by Mansell (2006).

Finally, Tüzün et al. (2015) propose a decision support system named TransitPL⁴ that assists decision-makers in evaluating factors related to an organization's preparedness to adopt PLE, and to identify strengths and weaknesses with regard to strategies for adopting a PLE approach. The authors provide a set of factors that impact decision-making with regard to adopting a PLE approach and organize these factors into four dimensions: Business, Process, Architecture and Organization. They operationalize the evaluation through a decision support system that uses a scheme of questions and possible answers for each question. Nevertheless, this approach does not evaluate motivation and lacks empirical evidence to support the practical usefulness of its proposed evaluation factors.

A further approach identified was Pure Systems⁵ which has its own method for evaluating a customer's preparedness to adopt a PLE approach. However, no further details about this method were found online.

2.1.2 Implementation stage

This section first looks at approaches that aim to evaluate ongoing product line engineering adoption initiative and secondly, it describes strategies for implementation once the decision to adopt a PLE approach has been made. Finally, this section presents approaches interested on evaluating economic conditions to adopt a PLE approach.

²www.biglever.com

³www.tecnalia.com/es/

⁴Decision support system: information system designed specifically to support business or organizational decision-making activities (Power 2002).

⁵<https://www.pure-systems.com/pureconsult>

Approaches that evaluate ongoing PLE adoption initiatives.

The Family Evaluation Framework is one of the best-known evaluation frameworks in the PLE field ([van der Linden et al. 2004, 2007](#)). This framework helps organizations to evaluate an ongoing product line engineering project across four dimensions: *business, architecture, process and organization*. These dimensions are broken down into factors which serve to depict the maturity of each dimension on a five-level scale. As a result of the evaluation, the framework provides an evaluation profile that indicates a level of maturity for each of the dimensions under evaluation. For example, an organization whose business dimension is evaluated as “project-based” is at a maturity level where product line engineering practices do not exist and there is only a short-term vision with no strategic planning ([van der Linden et al. 2007](#)).

The Family Evaluation Framework describes what should be done to achieve each maturity level, but does not propose any tools to make the evaluation operational. To improve this limitation, [Ahmed and Capretz \(2005, 2010, 2011a, 2011b\)](#) put forward an evaluation methodology that has the same focus as the Family Evaluation framework but offers more detailed information on the “how” of operationalizing the evaluation. In particular, this methodology includes specific questions for each dimension which are scored using a qualitative ordinal scale. Additionally, the evaluation methodology proposed by [Ahmed and Capretz](#) explains procedures for calculating the level of maturity in each dimension from the collated responses. More recently, [Lindohf et al. \(2021\)](#) present a report of their experience tailoring, extending and applying the Family Evaluation Framework in order to evaluate nine medium to large product lines of aircraft simulators.

[Saarlo \(2009\)](#) proposes a Software Product Line Engineering Maturity Model based on available theory and case studies published about PLE. This maturity model provides an overview of activities needed to implement a product line engineering initiative. At the highest level of abstraction, the maturity model has four *dimensions: Business, Domain Engineering, Application Engineering, and Collaboration*. These dimensions are broken down into *practice areas, sub-practice areas and example actions*. Practice areas are factors required for the success of a PLE initiative and *example actions* are concrete ways of implementing these practice areas.

[Matturro & Silva \(2005\)](#) have created a method to identify gaps in the knowledge that an organization has and the knowledge it needs to transit towards a PLE approach. The conceptual basis for this evaluation are the 29 practice areas of the SEI Software Product Line Practice Framework ([Clements & Northrop 2001b](#)). At an operational level, the method uses two templates with matrices to cross-reference an organization’s current knowledge and experience against what it needs to know. The intersections of the comparison represent the knowledge that the organization has, while blank intersections represent the gaps in knowledge that an organization must fill in order to be prepared to adopt a PLE approach.

The ASPLA assessment model ([Hohl et al. 2018](#)) defines aspects that should be considered in order to self-evaluate the current state of agile software development in combination with software product lines. This model was primarily designed for the automotive domain and defines what should be evaluated around seven dimensions: Product Line Architecture, Domain Requirements Engineering, Agile Software Development, ContinuousX, Continuous Model Improvement, Testing Strategy, and Communication. Conceptually, this model is based on a literature review, an interview, and challenges identified in an empirical evaluation. Additionally, the authors provide an online tool to conduct the evaluation⁶.

Although these approaches may be useful when product line engineering is up and running, they are inadequate for organizations that are in the early stages of the decision process of PLE adoption for the following reasons:

- People in charge of the evaluation need to be proficient in product line engineering practices in order to

⁶www.aspla.org

understand the evaluation and its results.

- The actors and questions included in the evaluation assume that the adoption decision is already made and therefore do not evaluate the motivation or the preparedness that organizations have for initiating a product line engineering approach.

Approaches that guide the adoption of a PLE approach.

Organizations can introduce product line engineering practices all at once, using a big-bang approach, or through incremental increases in personnel, processes, resources or outputs (Böckle et al. 2002). Descriptions of both strategies are presented below, and then specific approaches that have been identified are discussed.

- **Big-bang.** Under this strategy, organizations adopt a PLE approach for the whole organization all at once. This approach can be appropriate for organizations that are highly motivated to adopt PLE and are able to freeze their software development to dedicate their entire resources to such an initiative (Böckle et al. 2002). However, experience reports (Muthig 2001) and experts in organizational change (Kotter & Cohen 2002) advise following an incremental transition rather than a big-bang approach in order to avoid radical changes and reduce change barriers.
- **Incremental.** Using this strategy, the PLE approach begins with limited resources that increase gradually, in line with an organization's results. This strategy aims to reuse existing structures as much as possible to reduce barriers and get people on board with the initiative. There are different options for an incremental adoption (Böckle et al. 2002):
 - **Personnel - Incremental Introduction.** Only a small group of people in the organization is involved with the product line engineering initiative. Other people are added/reorganized incrementally, according to the results (Böckle et al. 2002). This strategy is useful when the organization has pressures that force it to continue with its normal activities (such as support, maintenance, and product development) while simultaneously carrying out the adoption of a PLE approach (Björklund & Jonas Hjelmar 2010).
 - **Process - Tactical Introduction.** The organization involves only specific areas where problems can be solved by using product line engineering. The remaining areas continue using their current practice. In this case, the adoption concentrates its attention on solving the most urgent needs of an organization (Böckle et al. 2002, Pohl et al. 2005).
 - **Resources - Incremental Investment.** The initiative starts with a reduced budget that increases as the organization obtains results. In this case, organizations need to plan which activities they will fund to start the product line because a greater portion of resources remain dedicated to conventional product engineering (Böckle et al. 2002).
 - **Outputs - Pilot First.** The intended output is a pilot in the form of a prototype, toy product, an extension of an existing set of products, or a new product which is the first member of a product line. Organizations can stop the PLE project after the pilot if the results are not satisfactory (Böckle et al. 2002, Pohl et al. 2005). Bröckers (2018) states that one limitation of the pilot project strategy is that incomplete domain knowledge may limit the variability included in the product line. He proposes an "extended pilot" strategy in which several organizations in the same domain create a pilot project using their shared knowledge about the domain.

Three specific approaches that follow variations on the incremental adoption theme are described below:

The *Adoption Factory* pattern (Northrop 2004) is an organizing structure proposed by the SEI that guides

an organization towards setting up a product line development strategy in three stages: *setting the context, establishing the production capacity and operating the product line*. The *framework for Software Product Line Practice* (Clements et al. 2012) groups 29 practice areas under these three stages, where a “practice area” is defined as a “collection of activities that an organization must master to successfully carry out the essential work of a product line”. Practice areas, or areas of expertise, in turn, are organized according to three categories: Organization Management, Technical Management and Software Engineering. Thus, PLE adopters can identify which practice areas are more important depending on the stage of the adoption process. Additionally, Jones & Northrop (2005) explain how to use the Adoption Factory pattern in organizations with CMMI-based process improvement practices.

Bosch (2005) also suggests that product line adoption evolves through three stages: *initial adoption, expanding scope and increasing maturity*. The *initial* adoption phase ends with the successful integration of shared artifacts into at least two products. This result demonstrates that the organization can successfully adopt a PLE approach. The second *expanding scope* stage would, for example, extend the functionality of included features into the product line. Finally, in the third stage, the organization increases the maturity of the product line artifacts to reduce product derivation costs.

BigLever proposes another incremental methodology: the *3-Tiered SPL Methodology* which considers an incremental tactical transition approach, incremental investments and incremental expected outputs (Krueger 2007). This methodology uses three milestones to gradually incorporate PL capabilities in organizations that already have a product portfolio and want to migrate to a PLE initiative. To achieve the first milestone, organizations use product line variation techniques, instead of ad-hoc techniques, to reduce effort overload and defects caused by asset duplication. For the second milestone, they design their product portfolio as a single system rather than as a multitude of separate products, allowing them to optimize the quality of their product portfolio. Organizations achieve the final milestone when their portfolio is governed by features and not by products, which reduces their time to market and increases their ability to generate products.

Approaches that evaluate economic conditions

An early attempt to evaluate the economic conditions of product lines was created by Poulin (1997), which addressed the issues of software reuse metrics and cost models. This method proposes two metrics to compute Reuse Cost Avoidance (RCA): the Relative Cost of Reuse (RCR) and Relative Cost of Writing to Reuse (RCWR).

Later, Knauber et al. (2002) provided an economic model for product lines using seven hypotheses which quantified the behaviors of the potential benefits of product line engineering. This model was a starting point for economic models that were later developed to quantify the economic costs and benefits of adopting product line engineering.

In 2003, Cohen (2003) put forward an economic model based on the products that an organization plans to deliver, the projected cost savings and the actual costs of reuse the organization would incur while developing and using product lines. The following year, Böckle et al. (2004) posited seven reuse scenarios that would produce a cost estimate for an adoption of the PLE approach. Also in 2004, Buckle et al. (2004) introduced the first version of a product line costing model. This built on the scenarios from Böckle et al. (2004) to calculate expected costs and benefits, in terms of cost savings, that an organization could expect in line with the proposed scenarios. The authors illustrated their reuse model with a running example. Shortly after, Clements et al. (2005) consolidated and extended the work of Buckle et al. (2004) and Böckle et al. (2004), and put forward the SIMPLE economic model, which aims at estimating the effort and cost savings of adopting product lines in an organization.

Other economic models in the literature proposed for when an organization needs to make a decision to either embrace software reuse or not are: COPLIMO (Boehm et al. 2004), ICSMSR (Ali Mili et al. 2001),

SocoEMO-PLE (Sana Ben Abdallah Ben et al. 2005), INCOME (Nóbrega et al. 2008). These economic models have been compared in, for example, Ali et al. (2009), Góngora Blandón & Picota Cano (2012), Khurum et al. (2008), Parmeza (2015), Heradio et al. (2018). Additionally, Peterson (2004) puts forward a framework for economic analysis based on the author’s experience with PLE adoption at Convergys. Finally, Krüger et al. (2016) extend the cost functions of SIMPLE by considering the re-engineering of legacy systems instead of developing a software product line from scratch. However, the authors do not provide any concrete operationalization of their proposal and therefore it remains at a theoretical level.

Regardless, these approaches that evaluate economic conditions are more interested in performing cost-benefit analyses and assume that motivation and preparedness to carry out a successful adoption are given factors.

2.2 Q2 - How do these approaches operationalize an evaluation of the convenience of adopting PLE?

From the approaches published in the literature, this section analyzes those that are related to the *initiation* stage of the *innovation decision process* as these are the approaches most closely related to the area of knowledge addressed by this research.

Four of the approaches presented in Q1 addressed the potential that a domain has for elaborating products using a product line approach : *Product Line Potential Analysis Method* (Fritsch & Hahn 2004), Bandinelli & Sagardui (2000)’s domain potential analysis, the *PuLSE-eco* method (Schmid & John 2002), and ABB’s proprietary method (Koziolok et al. 2013, Domis et al. 2014, Koziolok et al. 2016); and a further four evaluate whether necessary conditions for adopting a PLE approach exist in organizations: *Product Line Technical Probe - PLTP* (Northrop et al. 2005), *onePLE solution* (BigLever Software 2018), Tecnalia’s *Reuse-invest* and *Reuse-check* method (Mansell 2006), and *TransitPL* (Tüzün et al. 2015). This section analyses each of these evaluation approaches in terms of *i*) how the evaluation should be carried out (see Section 2.2.1) and *ii*) the content (see Section 2.2.2). Table 2.1 summarizes the content of this section considering both categories the content and the evaluation design and execution.

Table 2.1: Summary of related literature that have addressed how to assist organizations in their decision to whether adopt or not a PLE approach. Source: author’s analysis

Approach	Description	Concern	Content		Evaluation design and execution		
			Provided details		Evaluation time span	Evaluation strategy	Availability
Bandinelli & Sagardui (2000)	Conceptual framework that proposes high level criteria for evaluating to what extent a potential domain serves for product line purposes	Domain of interest	List of factors only		Some days	Need consultants	Public
Schmid & John (2002)	Evaluates benefits, risks and economic costs for domains that could be considered for a PLE initiative	Domain of interest	List of factors only		Some days	Need consultants	Public
Koziolok et al. (Koziolok et al. 2013, Domis et al. 2014, Koziolok et al. 2016)	Evaluates to what extent a set of independent products have the potential to be structured as a product line. This method customizes the PLTP method	Domain of interest	List of factors & Rationale for inclusion & Results of application		Some days	Need consultants	Internal use only - ABB

This table continues on next page

Approach	Description	Content		Evaluation design and execution		
		Concern	Provided details	Evaluation time span	Evaluation strategy	Availability
Fritsch & Hahn (2004)	Evaluates whether a domain has the potential to be used for product line purposes according to its target market and potential products	Domain of interest	List of factors & Examples of some questions to include	Half a day	Need consultants	Internal use only - Bosch
<i>Product Line Technical Probe - PLTP</i> (Northrop et al. 2005)	Useful for evaluating organizations' preparation for adopting PLE or for identifying problems when companies are already running a PLE initiative	Evaluate preconditions to adopt PLE	List of factors & Report of experiences on how this approach works in practice	Months of work	Need consultants	Commercial use
<i>onePLE solution</i> (BigLever Software 2018)	Solution that leads to a repeatable for organizational transformation. Based on the feature-based product line approach	Evaluate preconditions to adopt PLE	General description available online	Some days	Need consultants	Commercial use
<i>Reuse-check</i> (Mansell 2006)	Reuse-Invest helps to decide if it is economically profitable to adopt systematic reuse. Reuse-Check assesses if the organization processes are ready for adopting systematic reuse practices	Evaluate preconditions to adopt PLE	List of factors to consider & Results of use this approach in six case studies	Some days	Need consultants	Internal use only- European Software Institute, ESI-Tecnalia
<i>TransitPL</i> (Tüzün et al. 2015)	Decision support system to assess organization preparation to adopt a PLE and identify the most convenient adoption strategy. It also includes charts that summarize the results	Evaluate preconditions to adopt PLE	List of factors & Rationale & Evaluation with one case study	Immediate results after completing the information	Self-evaluation	Public

2.2.1 Evaluation Design and Execution

With the exception of Transit-PL ([Tüzün et al. 2015](#)), seven of the eight approaches identified, use consultants to carry out the evaluation process. Transit-PL provides an online tool to operationalize their evaluation, but unfortunately the tool currently has technical problems that prevent interaction beyond the authentication page⁷. Other approaches such as those depicted in [Bandinelli & Sagardui \(2000\)](#), [Schmid & John \(2002\)](#), [Fritsch & Hahn \(2004\)](#), [Mansell \(2006\)](#), [Northrop et al. \(2005\)](#), [Koziolk et al. \(2016\)](#), [BigLever Software \(2018\)](#) need consultants to perform the evaluation process.

In the approaches that use consultants to lead the evaluations, the process of evaluation is generally broken down into three stages: *preparation*, *execution* and *analysis* ([Bandinelli & Sagardui 2000](#), [Schmid & John 2002](#), [Fritsch & Hahn 2004](#), [Mansell 2006](#), [Northrop et al. 2005](#), [Koziolk et al. 2016](#), [BigLever Software 2018](#)). During the *preparation* stage, consultants collect data regarding the context of the organization and select the organization's personnel who will participate in interviews. In the *execution* stage, consultants collect information through structured or semi-structured interviews. Finally, during the *analysis*, consultants analyze the collected information and create the evaluation outputs. The duration of the whole evaluation process varies widely

⁷Last reviewed on [<http://transitpl.herokuapp.com>], [Sept 20 - 2021]

between half a day (Fritsch & Hahn 2004), some days (Bandinelli & Sagardui 2000, Schmid & John 2002, Mansell 2006, BigLever Software 2018, Koziolok et al. 2016) and months of work (Northrop et al. 2005).

It was noted that most of the approaches only provide a list of factors or, at most, a description or rationale for each factor. For example, Bandinelli & Sagardui (2000) introduce risk, benefit and cost factors but do not break them down. The Product Line Potential Analysis method (Fritsch & Hahn 2004) lists factors but does not justify their inclusion, and while the authors provide examples of the detailed questions, they do not make the whole set of questions available for free access. This is also the case for the domain evaluation model from ABB (Koziolok et al. 2013, Domis et al. 2014, Koziolok et al. 2016), Tecnia's Reuse-invest method (Mansell 2006) and PulSE-eco (Schmid & John 2002). This lack of detail could be explained because these approaches are meant to be used with the support of consultants who know how to interpret the information and ask additional questions if necessary. While the guidance of consultants may guarantee that any recommendations are aligned to the context of specific organizations, it also implies investing effort and money in an innovation whose potential is unknown. Thus, the presence of experts in the evaluation process presupposes that organizations have the economic capacity to afford consultancy services, as well as the ability to identify that product lines would be the most convenient approach to meet their needs.

2.2.2 Content

Motivation is the psychological force that enables action (Touré-Tillery & Fishbach 2014). Looking specifically at factors that evaluate motivation for adopting a PLE approach, six of the analyzed proposals (PLTP, Tecnia's Reuse-invest, Product Line Potential Analysis, Transit-PLE, the domain evaluation from ABB, and the OnePLE solution) include at least one factor aimed at understanding the reasons that motivate organizations to consider adopting a PLE approach.

The PLTP method (Clements et al. 2005) includes questions such as *what is your motivation for using a product line approach?* and *what are your business goals for adopting a product line approach?* Tecnia's Reuse-invest approach (Mansell 2006) states that the staff should understand *the need to change current practices and the benefits that can be obtained*. The Product Line Potential Analysis method (Fritsch & Hahn 2004) uses three factors to identify whether organizations have problems that a PLE approach could address, such as *quality problems, complexity problems or differentiated products*. Transit-PL (Tüzün et al. 2015) includes *business motivation* as a factor in the evaluation. The domain evaluation model from ABB includes *purpose* and *motivation* as evaluation factors. Finally, according to its description, the OnePLE solution (BigLever Software 2018) helps organizations evaluate their motives for adopting a PLE approach, but there is no public information on details of this as the evaluation is carried out by experts directly with interested organizations.

However, newcomers might face a problem answering a straightforward question about their organization's motivation to initiate a PLE adoption. First, motivation is an abstract construct that is difficult to evaluate directly as the existing approaches do. For example, the temperature of a room or the response time of a web page are constructs that could be measured directly, but it is difficult to accurately evaluate the motivation of a team or an organization with a single question because motivation cannot be observed or recorded directly (Touré-Tillery & Fishbach 2014). Instead, motivation could be evaluated through factors that influence it and that, taken together, would represent it.

Second, newcomers may lack the necessary experience and knowledge to determine whether their motives are relevant or not to adopting a PLE approach. Likely, the reasons they have in mind may not be factors that would justify the adoption of PLE approach. As an example of this, the Product Line Potential Analysis method (Fritsch & Hahn 2004) asks about *quality problems* as a motivation for adopting a PLE approach. A PLE

approach is neither the only, nor necessarily the best alternative to achieve better quality, as quality problems may stem from many different causes: developers do not test before delivering products to production; the organization does not follow a rigorous deployment process; there is no test team to detect bugs, etc. In these examples, an organization could solve its quality problem by improving its organizational practices and therefore adopting a PLE approach is not the solution. The same situation may occur with other general reasons for adopting a PLE approach such as quality improvement, time to market reduction or cost reduction.

Regarding the preparedness, in contrast to the evaluation of motivation where the approaches ask directly about reasons that motivate organizations to adopt a PLE approach, different factors have been included to evaluate conditions that denote an organization's preparedness to adopt a PLE approach. For example, factors such as process maturity, organizational support, market potential, openness to change, management support, domain knowledge, software engineering capability among others have been identified. The number of factors that each proposal includes, as well as their names, vary among the approaches. Table B.2 in Appendix B compares the factors that each proposal includes for evaluating preparedness. Rows indicate the set of factors included and columns show the name of each approach analyzed. The intersection between rows and columns contains the name that each proposal assigns to the factor. The number of factors that each proposal includes, as well as their names, vary among the approaches. For example, Transit-PL (Tüzün et al. 2015) and PLTP (Northrop et al. 2005) both include a factor called *process maturity*, while PulSE-eco (Schmid & John 2002) names the same factor *maturity*, and Tecnalia's *Reuse-invest* names it *management process*. The approach that includes the greatest number of factors is Transit-PL (Tüzün et al. 2015).

However, none of the approaches proposed have considered whether there are different levels of importance among those factors. Rather, each approach has included its own set of factors depending on its scope. For example, the approaches that only evaluate the domain (Fritsch & Hahn 2004, Bandinelli & Sagardui 2000, Schmid & John 2002, Koziolok et al. 2013, Domis et al. 2014, Koziolok et al. 2016) do not consider organizational factors such as the *product line awareness* or the *commitment of key actors*. Therefore, it is difficult for newcomers to know, in terms of preparedness to adopt a PLE approach, whether all the factors are equally relevant for an evaluation, whether non-compliance with some factors would be a reason to discard the adoption, or whether there are some factors that are desirable but not indispensable.

2.3 Q3 - What gaps exist in current approaches and what challenges will be faced in the future?

The literature review conducted in the scope of this research revealed only eight approaches that have addressed how to assist organizations in their decision to whether adopt or not a PLE approach. Some of these approaches are interested in evaluating the potential of a domain to initiate product line engineering (Fritsch & Hahn 2004), (Bandinelli & Sagardui 2000), (Schmid & John 2002), and Koziolok et al. (Koziolok et al. 2013, Domis et al. 2014, Koziolok et al. 2016). Some others propose solutions in which expert consultants could be of help for understanding the current situation of organizations with respect to adopting a PLE approach: *Product Line Technical Probe - PLTP* (Northrop et al. 2005), *onePLE solution* (BigLever Software 2018), the *reuse-invest* and *reuse-check* (Mansell 2006). Finally, there is an approach that provides an alternative to assist organizations to self-evaluate their preparedness for adopting a PLE approach (Tüzün et al. 2015).

Table 2.2 presents a comparison of the support offered by the approaches that currently exist in the literature along six dimensions. Three of these relate to the coverage that each approach includes to the initiation stage of the innovation adoption model: motivation to adopt PLE, preparedness to adopt PLE, and relative importance.

The other three dimensions relate how the evaluation is designed and executed and include: self-evaluation support, tool support, and open access.

Table 2.2: Gaps of related literature. Source: author’s analysis.

Approach	Coverage to the initiation stage			Evaluation design and execution		
	Motivation for adopting PLE	Preparedness for adopting PLE	Relative importance	Self-evaluation support	Tool support	Open access
Bandinelli & Sagardui (2000)	○	●	○	○	○	●
Schmid & John (2002)	○	●	○	○	○	●
Koziolek et al. (Koziolek et al. 2013, Domis et al. 2014, Koziolek et al. 2016)	○	●	○	○	○	●
Fritsch & Hahn (2004)	○	●	○	○	○	●
<i>Product Line Technical Probe - PLTP</i> (Northrop et al. 2005)	○	●	○	○	○	○
<i>onePLE solution</i> (BigLever Software 2018)	○	●	○	○	○	○
<i>Reuse-check</i> (Mansell 2006)	○	●	○	○	○	●
<i>TransitPL</i> (Tüzün et al. 2015)	○	●	○	●	●	●

●: Full Support, ●: Partial support, ○: No support

The most important elements of the table are highlighted below.

- **Motivation.** As presented in response to question Q2, none of the current approaches evaluate why a product line approach might be useful for an organization in the first place. Instead, some of the approaches ask directly for reasons that motivate the adoption. However, this strategy is problematic. Even if newcomers are aware of their own weaknesses, they do not have enough PLE experience to conclude whether a PLE approach is the right alternative to address their needs.
- **Preparedness to adopt PLE.** Each approach included its own set of factors which are also detailed at different levels of abstraction. Approaches evaluating the domain of interest were classified with a partial support as they do not include organizational factors, while approaches that evaluate preconditions to adopt PLE had the full support sign in Table 2.2. Table B.2 in Appendix B compares the factors that each proposal includes for evaluating preparedness.
- **Relative importance.** None of the approaches proposed have considered whether there are different levels of importance among the evaluated factors.
- **Self-evaluation support.** Seven of the eight approaches rely on the PLE experts and their knowledge to conduct the evaluations. Table 2.2 shows that Transit PL offers a partial support because the authors want to provide a solution that offers autonomy to newcomers. However authors’ proposal depends on their supporting tool and at the time state of the art was carried out, TransitPL had access difficulties.

- **Tool support.** A tool that assists in the evaluation is important to facilitate the evaluation and reduce barriers to entry. For example, a tool can help automate the operationalization of the evaluation in terms of capturing, processing and visualizing the results. Transit-PL (Tüzün et al. 2015) is the only approach that provides a self-evaluation tool, which included a scoring system for the evaluations' factors results and summary charts. However, as mentioned before this tool had access difficulties, therefore in practical terms newcomers cannot use it.
- **Open access.** Only three of the proposals are freely available to the public (Bandinelli & Sagardui (2000), Schmid & John (2002), TransitPL). Three others were designed for internal use (Koziolek et al. , Fritsch & Hahn (2004), Reuse-check). PLTP (Northrop et al. 2005) and onePLE (BigLever Software 2018) on the contrary are commercial solutions. Therefore must request and pay for consulting services to access to their services.

Taking into account the information shown in Table 2.2 there are two limitations that provide a rationale for this study: (i) a lack of an integrated approach to evaluate the convenience of adoption; and (ii) a dependence on the PLE experts and their knowledge to determine the convenience of adopting a PLE approach.

- **LIMITATION # 1. Lack of an integrated approach to evaluate the convenience of adoption.** Two activities take place during the *initiation* stage, before an organization decides to adopt or reject an innovative idea. The first activity is oriented towards identifying the motivation for considering an innovative idea, while the second activity is oriented towards identifying the preparedness of an organization to put the idea into practice. None of the analyzed approaches fully covers the two activities that belong to the *initiation* stage of the adoption process, although both activities occur when new initiatives are adopted in organizations. Organizations therefore need to identify and use different approaches to obtain a more complete picture. However, as mentioned above, not all approaches are available or fully documented for use.

A solution that builds on existing practices and integrates the various factors and results into a single evaluation would be useful to leverage existing knowledge in this regard and provide information to assist newcomers in evaluating the convenience of adopting a PLE approach.

- **LIMITATION #2. A dependence on the PLE experts and their knowledge to determine the convenience of adopting a PLE approach** Most of the approaches analyzed list for example factors that are useful to evaluate an organization's preparedness, but they do not provide the details that would allow newcomers to operationalize them. For example, five of the approaches include *process maturity* as a factor to evaluate. One question that a newcomer may have about this factor could be: *what aspects of the processes should be evaluated to determine if my organization has process maturity? Which data do I need to ask? How can I interpret the results?* The lack of detail needed to operationalize the evaluations may be due to the fact that all of the proposals, excepting Transit-PL (Tüzün et al. 2015), use a workshop-type evaluation format that requires experts to guide the evaluation.

In many circumstances, expert guidance is undoubtedly an excellent way to evaluate the convenience of adopting product line engineering according to an organization's context and needs. Indeed, most of the evaluation approaches considered in this thesis rely on experts to perform the evaluation. However, paying for expert guidance is problematic when the relevance of the solution is still uncertain. Organizations are usually in a better position to invest when they are confident of the success of an initiative, but in the early stages of the adoption process it is premature to assume such success.

A self-evaluation approach is, therefore, more suitable in the *initiation* stage of an innovation decision process.

Indeed, while some research initiatives provide self-evaluation tools (Davis 1993, Software Productivity Consortium 1993, Tüzün et al. 2015, Ahmed & Capretz 2011b, 2010, 2011a, 2006, Hohl et al. 2018), these are mostly for ongoing PLE initiatives and do not provide help for newcomers to discover whether a PLE approach could be convenient for their organization.

There is therefore a need for an alternative approach that can help organizations to self-evaluate the convenience of continuing with a PLE adoption, when the idea of PLE is just barely being considered. Once organizations are able to do this, they will have more arguments to support their decision and can then hire experts to advise them on how to move forward with the adoption process.

It was noted that most of the approaches related to this research were proposed in the early days of the product line engineering community. This explosion of related publications may be due to the fact that between 2000 and 2005 product line engineering was a cutting-edge topic in its early stage. For example, at that time, European companies, as well as US companies, had strategic product line initiatives (Schmid et al. 2021). Moreover, laying the groundwork for the PLE adoption was critical to boosting the adoption process.

Over the years, the field diversified and it seems that academic community's interest in organizational-related topics decreased. For example, in the last years, variability management and modeling (Raatikainen et al. 2019) have gained focus, while organizational topics such as the one addressed in this research have been barely addressed. One reason that could explain this lack of interest is that even if organizational topics are relevant to software engineering in practice, they need a business and organization perspective, which is not typically included in software engineering research (Rabiser et al. 2018). However, those concerns are still relevant nowadays. For example, Azanza et al. (2021) conducted a systematic literature review based on the 194 industrial studies reported in the software product line conference between 2000 and 2020. In their analysis, the authors raise the interest towards three key concerns that newcomers should reflect upon: product line evangelization, organization persuasion, and product line architecture. In this sense, a ready-to-use solution that allows newcomers to evaluate both motivation and preparedness for adopting a PLE approach would contribute to the product line evangelization and organization persuasion.

2.4 Summary of Chapter 2: State-of-the-art

This chapter presents and discusses the state of the art by answering three questions: *Q1 - What approaches currently exist that assist newcomers to PLE to evaluate the convenience of adopting a PLE approach or to evaluate ongoing initiatives?* *Q2 - How do these approaches operationalize an evaluation of the convenience of adopting PLE?*, and *Q3 - What gaps exist in current approaches and what challenges will be faced in the future?*

In order to answer these questions, the first section of this chapter (see Section 2.1) presents eight approaches from the literature that may assist newcomers to PLE to evaluate the convenience of adopting a PLE approach. In addition, this section describes approaches that are useful for evaluating ongoing adoption initiatives and strategies proposed in literature to conduct the adoption.

Then, Section 2.2 compares the content, structure, results and evaluation design of the different approaches in order to analyse how they operationalize the evaluation.

Finally, Section 2.3 identifies two limitations found in the current literature: LIMITATION #1. Lack of an integrated approach to evaluate the convenience of adoption and LIMITATION #2. A dependence on the PLE experts and their knowledge to determine the convenience of adopting a PLE approach. These limitations justify and motivate the research presented in this thesis, the evaluation framework **APPLIES**.

The next chapter, therefore, presents the methodological details that explain how the framework **APPLIES**, was designed and evaluated.

CHAPTER 3

Methodological details

The previous chapter (Chapter 2) presented key concepts for understanding the context of this research and analyzed the related literature. The review of the literature identified four gaps in existing approaches that evaluate conditions for successful adoption of a PLE approach. Addressing those gaps is the main motivation of this thesis.

This chapter describes how the research was designed and conducted. The first section presents the research methodology; the second section introduces the phases of the research; and finally, the third section presents the strategies carried out to reduce biases that could undermine the validity of the results. The chapter ends with a summary that synthesizes its content.

3.1 Research methodology

This research uses Design Science Research (DSR), a methodology frequently employed in information systems. Its main objective is to create, using a rigorous process, a purposeful artifact that people will use to improve something in a real context (Hevner et al. 2004, Wieringa 2014).

The objective of this research is aligned with DSR principles because:

- *The research addresses a practical problem.* Organizations need to evaluate the convenience of adopting a PLE approach. They need a rationale to justify the decision of whether or not to adopt a product line engineering approach.
- *The problem is solved by designing an artifact.* According to Wieringa (2014) an artifact *is something created by people for some practical purpose*. This artifact is a framework named **APPLIES** that helps stakeholders to evaluate the convenience of adopting a PLE approach by considering why PLE is needed in the first place and the organization's preparedness to carry out the adoption.
- *The designed artifact is involved with the context.* **APPLIES** intends to be useful for people considering adopting a PLE approach, which means it has a practical purpose. Moreover, eight empirical evaluations that involved practitioners, potential practitioners and researchers in product line engineering were carried out to evaluate **APPLIES** in real contexts.

Peffer et al. (2007) proposes six activities for DSR: (i) *identify problems*, (ii) *define the objectives for a solution*, (iii) *design and develop*, (iv) *demonstrate*, (v) *evaluate*, and (vi) *communicate*. These activities guide the research presented here.

Activity i. Identify problems. Any design science research should start by identifying the research problem that motivates the creation of an artifact (Peffer et al. 2007). The problem was identified based on this author's own experience when contributing to different projects aimed at applying product line

engineering concepts to real environments. In each of those projects, there was a question that I often asked myself: *how could I help organizations to identify whether product line engineering is the right approach to fulfill their needs?* With this question in mind, the literature review was carried out, identifying and analyzing published approaches that contribute in some way to evaluating the conditions required to adopt a product line engineering approach (see Chapter 2).

The results of this review show that there is room for improvement, which motivated this research.

Activity ii. Define the objectives of a solution. This activity consists of defining the objectives and requirements for the proposed artifact (Peppers et al. 2007). As presented in Chapter 1, the objective of this research is *to design and evaluate a framework that will aid newcomers to product line engineering to evaluate to what extent and why product line engineering is, or is not, convenient for their organization.* Chapter 4 presents the requirements that the proposed artifact, **APPLIES**, is intended to meet.

Activities iii, iv and v. Solution design, demonstration and evaluation. These activities consist of creating the research artifact, proving that the idea works and evaluating it. In this research, these activities were conducted in two phases: *construction* and *evaluation*. During the *construction* phase, the research artifact, named **APPLIES**, was designed and developed. During the *evaluation* phase **APPLIES** was evaluated through eight complementary empirical experiences. The collected evidence was cross-analyzed to find evidence on the ease of use, content pertinence, perceived usefulness and intention to use of **APPLIES**. Section 3.2 explains the *construction* and *evaluation* phases in detail.

Activity vi. Communication. As the research progressed, five scientific articles were published: four were presented at scientific events (Rincon, Mazo & Salinesi 2018a, Rincon, Chavarriaga, Mazo & Salinesi 2018, Rincon et al. 2019, 2020), and one in a journal (Rincon, Mazo & Salinesi 2018b). All publications were grouped into a Research Gate project¹ that makes the work available to peers in the scientific community. As of December 2021, the project overall has received more than 171 reads. **APPLIES** was also presented, as an invited talk, at the 6th International Workshop on Reverse Variability Engineering, REVE, held in conjunction with the 22nd International Conference of Software Product Lines². In terms of dissemination, during the evaluation stage **APPLIES** was presented to individuals from the industry who have experience in software engineering, and to academic and industry experts in product lines. In addition, a website presenting the project is available for free consultation by the community³. From this website people can access the tool that supports the latest version of the framework. As of December 2021, the tool has had 203 downloads and the website has received visits from people in Colombia, United States, Mexico, Spain, France, Italy, Sweden, Finland and Germany.

3.2 Construction and evaluation phases

The design-science cycle activities related to the solution design and its evaluation took place in two phases: *construction* and *evaluation*. During the *construction* phase, the **APPLIES** framework was developed. **APPLIES** is the solution proposed in this research to address the limitations identified in Chapter 2. This framework intends to assist newcomers to evaluate an organization's motivation and preparedness for adopting a PLE

¹<https://www.researchgate.net/project/APPLIES-framework-for-evaluating-organizations-motivation-and-Preparedness-for-adopting-product-LInES>

²This workshop took place on September 10, 2018.

³www.applies.variamos.com

approach. Next, in the *evaluation* phase, **APPLIES** was evaluated with regard to its ease of use, content pertinence, perceived usefulness and intention to use. Suggestions for improving **APPLIES** were also collected. The evaluation phase used a complementary multi-method approach in which eight empirical evaluations that involved different stakeholders and settings were planned and executed. The material resulting from the evaluations was collated and analyzed.

The following subsections introduce the methodological details of each phase and Figure 3.1 presents the details of each phase.

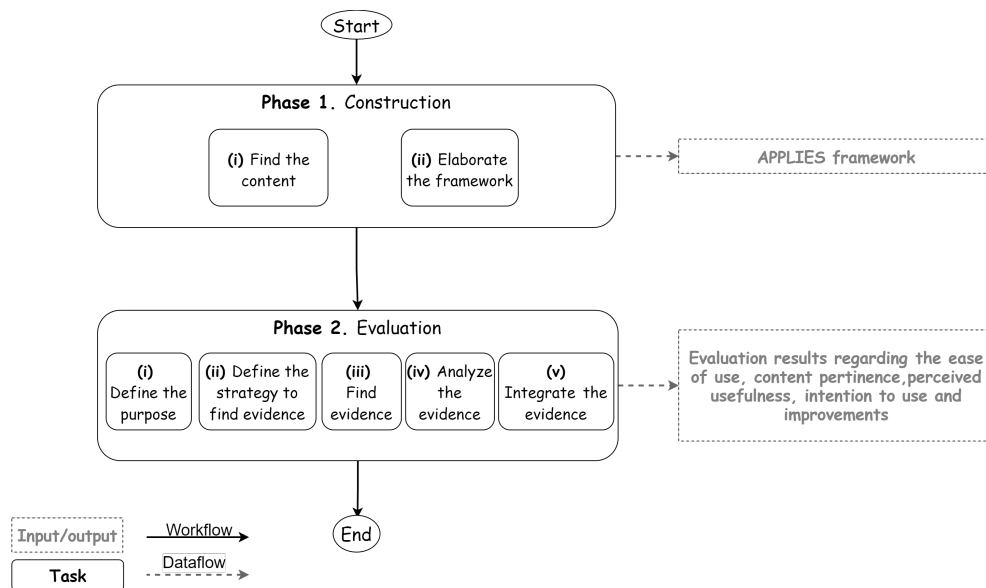


Figure 3.1: Details of the phases that took place to design and develop the research artifact and then to evaluate it. Source: developed from Ahlemann & Gastl (2006) and O’Leary et al. (2012)

The following subsections introduce the methodological details of each phase.

3.2.1 Phase 1. Construction

The objective of this phase was to develop the research artifact which is the **APPLIES** framework. This phase had two stages: (i) find the content and (ii) create the framework. Both stages are explained below.

3.2.1.1 Find the content

This stage aimed to find and analyze literature that could serve as input to explain why organizations have been interested in adopting a PLE approach and what pre-requisites they should satisfy for a successful adoption. This section explains how the literature was identified, selected and analyzed to constitute the conceptual basis of **APPLIES**. This review aimed to identify information that answered the following questions:

- Why have organizations adopted a PLE approach?
Rationale. The purpose of this question is to identify what factors have motivated organizations to adopt a product line engineering approach.
- What are the barriers and enablers that organizations must overcome for adopting a PLE approach?
Rationale. The purpose of this question is to identify key factors that an organization should consider to adopt a PLE approach with success.

Search strategy. First, an automatic search was done on Google Scholar using the tool Publish or Perish⁴. Google Scholar provides a wider coverage than Scopus or Web of Science because it includes results from all digital libraries such as IEEE Explore, ACM Digital Library, SpringerLink and Science Direct, as well as grey literature.

Two types of keywords were used in the automatic search: general words about product lines (i.e., “*product line engineering*”, “*core asset*”, “*product line*”, “*domain engineering*”, “*application engineering*”, “*product-line*”, “*product-family*”, “*product family*”, “*product families*”, “*system family*”), and specific words related to the adoption of the product lines (“*introduction*”, “*transforming*”, “*transitioning*”, “*maturity*”, “*introduce*”, “*adapting*”, “*adopting*”, “*adoption*”, “*initiating*”, “*institutionalization*”, “*institutionalizing*”, “*introducing*”, “*launching*”, “*migrating*”, “*migration*”, “*potential*”, “*transition*”, “*introduce*”, “*feasibility*”, “*experience*”, “*experiences*”, “*successful*”).

The scope of this search was limited to literature published up to October 2017. No starting period was defined because Publish or Perish is able to find references indexed in Google Scholar without limiting a starting point in time. The results of the search were exported from Publish or Perish to CSV and were merged in Excel to remove duplicated references. In total, 384 non duplicate references resulted from this process. Additionally, this stage included a backward snowballing strategy for publications that had similar themes to those addressed in this thesis, such as [Bandinelli & Sagardui \(2000\)](#), [Fritsch & Hahn \(2004\)](#), [Tüzün et al. \(2015\)](#).

Two exclusion criteria served to filter the publications:

- *Exclusion criteria #1 - light filter:* This filter does not require a full text review as any paper was excluded if it was not accessible, duplicated, not written in English or was an editorial, position paper, keynote, review, tutorial summary or panel discussion.
- *Exclusion criteria #2 - relevance to the scope.* If the focus of the document was different from one of the following:
 - i Real experiences on the adoption/rejection of a PLE that explain why organizations decided to adopt PLE and the limitations they faced in the process (pure academic experiences were excluded);
 - ii Approaches to evaluate the adoption of a product line approach;
 - iii Methods to plan or execute the transition towards a product line approach;
 - iv Books about PLE;
 - v Proposals that evaluate the potential for adopting a PLE approach.

While 100 publications passed the two exclusion filters, only 40 articles were reviewed in detail to build the thematic networks. Table A.1 in Appendix A lists the papers used to build thematic networks. A thematic network is “*a web-like illustrations (networks) that summarize the main themes constituting a piece of text*” ([Attridge-Stirling 2001](#)). This difference between the selected references and the reviewed papers happened because the analysis of the collected data reached theoretical saturation. Theoretical saturation means that no additional data was found because the data started to be repetitive and new papers did not lead to new information ([Given 2008](#)). At this point, the analysis of the related literature stopped and the activity of elaborating the framework began.

Note that, in order to reduce the risk of having incomplete information, the second phase of this research

⁴<https://harzing.com/resources/publish-or-perish>

evaluated the relevance of the information included in the framework and identified the elements to be incorporated and eliminated from the conceptual models that emerged from this literature review. Section 5.2.6 in Chapter 5 summarizes the results found in this regard.

Data analysis

Thematic analysis is a method for identifying, analyzing, and reporting themes in order to organize and describe data-sets in detail (Braun & Clarke 2006). The thematic analysis in this research had two objectives: (i) to identify key factors that drive organizations to adopt a PLE approach, and (ii) to identify key factors to evaluate an organization's preparedness for adopting such approach. First, themes were identified in the selected publications. Next, the identified themes were organized using thematic networks (Attride-Stirling 2001). Thematic networks systematize the extraction of (i) lowest-order premises evident in the text, (ii) categories of basic themes grouped to summarize more abstract principles, and (iii) superordinate themes encapsulating the principal metaphors in the text as a whole (Attride-Stirling 2001). Figure 3.2 presents the thematic network used to organize factors that drive organizations to adopt a PLE approach.

Data analysis followed the three-step process proposed by Attride-Stirling (2001) to create the thematic networks on the topic of interest. The steps were: (i) coding the material, (ii) identifying the themes, and (iii) constructing the thematic networks.

- i **Coding the material.** In this step documents were coded and analyzed to extract themes of interest. First, seminal papers about product line adoption and literature reviews on this subject were reviewed to get familiar with the data. Seminal papers were identified by sorting the retrieved references in descending order, according to their number of citations. Then, the researcher reviewed in detail the literature associated with the adoption of a PLE approach, and extracted from them as many potential codes as possible. Next, passages, quotations or single words of the publications were coded with the previous codes. As coding is a dynamic process by nature, new codes were also created throughout the duration of the coding step (Saldaña 2013).
- ii **Identifying themes.** Once the set of publications was coded, the researcher combined related codes to create themes. This process was carried out over several discussion meetings with supervisors. Themes capture a common, recurring pattern across a data-set (Braun & Clarke 2006). The resulting list of themes was later filtered to merge similar themes and remove redundant ones.
- iii **Constructing thematic networks.** The list of derived themes was organized into similar groups with a different level of abstraction: basic themes, organizing themes and global themes. *Basic themes* are simple premises that contribute to the explanation of a super-ordinate theme (Braun & Clarke 2006). *Organizing themes* summarize the principal assumptions of a group of basic themes (Braun & Clarke 2006). Finally, *global themes* capture and summarize the core point of a coherent set of organizing themes (Braun & Clarke 2006). The results of the thematic analysis were structured according to the level of abstraction of the themes found.

3.2.1.2 Develop the framework

According to the Oxford Dictionary, **operationalization** is the process of transforming an abstract, theoretical concept which itself is not directly measurable into something concrete, observable, and measurable. Psychological constructs such as well-being, emotions, or learning progress are examples of abstract concepts that must be operationalized for their measurement (Emmerich et al. 2016). To operationalize an abstract concept implies defining: (i) what statements will represent the concepts under evaluation; (ii) how to collect the data; (iii) the

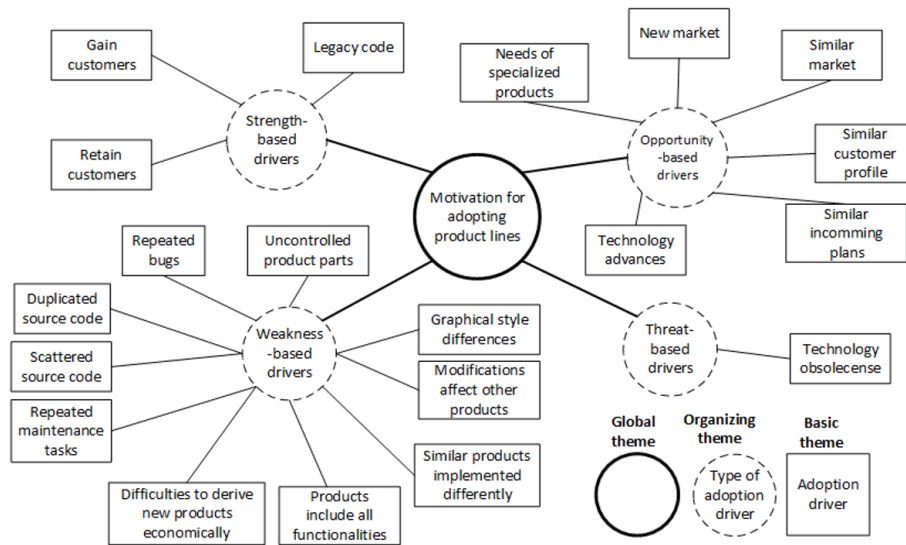


Figure 3.2: Resulting thematic network – why organizations adopt a PLE approach. Source: author’s data analysis.

rules for the evaluation; and (iv) how to interpret the results. This stage served to operationalize the evaluation of the convenience of adopting a PLE approach, using the factors identified in the literature that provide the basis for the contents of the questionnaire. Chapter 4 presents **APPLIES** which is the evaluation framework that resulted from this stage.

3.2.2 Phase 2. Evaluation

APPLIES was evaluated using empirical evaluations as it intends to solve a practical problem and will be used by people. This evaluation phase had five stages: (i) define the purpose, (ii) define the strategy for gathering evidence, (iii) gather evidence, (iv) analyze the evidence, and (v) integrate the evidence. These stages are introduced in the following sections and are similar to those proposed by [Forrest Shull & Raimund L. Feldmann \(2008\)](#) in their method for constructing theories from multiple sources of evidence.

3.2.2.1 Define the purpose

The evaluation presented here had a **formative** purpose because in addition to defining the performance of **APPLIES** around different factors, it was used to identify reasons that could explain the performance obtained, as well as to identify areas for improvement ([Davidson 2004](#)). **APPLIES** in itself is a new solution that seeks to assist those interested in adopting product line engineering to evaluate the convenience of such an adoption. Thus, as with any new product, it was anticipated that **APPLIES** would have errors and areas to improve, and identifying areas for improvement is essential for achieving desired performance in the future.

Determining the extent to which the results provided by **APPLIES** match the reality faced by organizations during the adoption of a PLE approach, as well as the extent to which **APPLIES** is used in practice is beyond the scope of this research. This information will only be available over time as organizations adopt a product line engineering approach and have data to compare the information delivered by **APPLIES** versus the strengths and weaknesses they actually find in the adoption.

In contrast, the evaluation carried out in this research aims to determine to what extent potential users perceived the value of using **APPLIES** in practice. [Davis \(1989\)](#) and [Moody \(2003\)](#) explain that people will

adopt or reject a solution based on their perceptions. The evaluation of **APPLIES**, therefore, was planned to evaluate three perceptual factors: *perceived usefulness*, *intention to use* and *ease of use*. The three factors are constructs of the Technology Acceptance Model (Davis 1989) and have been used to evaluate other proposals in the information system context (Röcker 2009, Abrahão et al. 2011, de Oliveira et al. 2014). A point worth noting is that although these three factors are subjective and represent the opinion of people, they are extremely valuable for evaluation, since people act according to their beliefs. For example, it is unlikely that users will embrace a solution if they do not believe it to be useful, even though objectively they may understand that the application will potentially improve their performance in certain tasks (Davis 1989).

In addition to the three factors described above, the *content pertinence* of **APPLIES** was also evaluated as this provides the conceptual basis that supports the evaluation.

Evaluation questions

The following questions guided this empirical evaluation.

- **EQ1: To what extent do users perceive **APPLIES** as easy to use and why?**

In the evaluation of **APPLIES**, *ease of use* is defined as the degree to which a user believes that using **APPLIES** is effortless, in line with Davis (1989).

Rationale. When a solution is not easily understandable, it is unlikely to be used or perceived as a high quality solution by its potential users (Matook & Indulska 2009). On the contrary, the easier it is to use a solution, the less effort is required to use it, which should benefit a user's performance (Davis 1989). **APPLIES** operationalizes the evaluation of convenience of adopting a PLE approach as a self-evaluation tool, using a self-report questionnaire. This means that people will use it as it is and there is no way to explain or re-frame the questions during use. Hence, questions have to be easy to understand and as simple as possible. Because of this, in the design of **APPLIES**, different design choices were made regarding the response formats to capture information, the charts that summarize the results, and the tool to enter data and obtain the results. The evaluations conducted served to collect evidence on ease of use to determine which elements work well and which elements need improvements.

- **EQ2: To what extent is the information included in **APPLIES** sufficient to evaluate the convenience of adopting a PLE approach?**

Rationale. This question serves to collect evidence that can be used to refine the content used in **APPLIES** to evaluate the motivation and preparedness of organizations to adopt a PLE approach.

- **EQ3: To what extent do users perceive the **APPLIES** framework as useful and why?**

Perceived usefulness is the degree to which users believe that **APPLIES** would be effective in achieving its intended objectives⁵.

Rationale. According to Davis (1989), users adopt a solution primarily because of the functions it may fulfill for them or, in other words, its perceived usefulness. This means that perceived usefulness is closely linked to potential acceptance of the solution. The goal of this question is to discover whether newcomers to PLE might consider **APPLIES** a useful solution and what factors might limit its usefulness.

- **EQ4: Would the practitioners use **APPLIES** themselves? Why or why not?**

Intention to use refers to the extent to which potential users of **APPLIES** would be willing to use it⁶.

⁵Definition adapted from Davis (1989), Abrahão et al. (2011).

⁶This definition was adapted from Davis (1989), Abrahão et al. (2011).

Rationale. Since ideally **APPLIES** would be used in real contexts, the aim of this evaluation question is to evaluate to what extent practitioners perceive value in using **APPLIES** in practice.

- **EQ5: What additions or modifications could improve **APPLIES**?**

Rationale. The requirements that guided the initial design of **APPLIES** came from the initial exploration of literature and personal initiative. The results from this question will be used to identify aspects that were not considered in the initial design and modifications that could make **APPLIES** better.

3.2.2.2 Define the strategy to find the evidence

A complementary multi-method strategy

APPLIES is intended to be used by people in real working environments. Thus, to evaluate its performance and identify aspects for improvement, this research used a multi-method empirical strategy. This strategy is based on the combination of complementary methods of empirical research that compensate for the inherent shortcomings of individual methods, thus reinforcing the validity of the results (Wood et al. 1999).

There are two options for designing multi-method empirical evaluations: an *evolutionary multi-method* and a *complementary multi-method* design (Wood et al. 1999). In the *evolutionary multi-method* design each empirical evaluation is performed one at a time and the results serve as inputs to define the next evaluation. In contrast, in a *complementary multi-method* design, the same phenomenon is studied independently through different evaluations, seeking confirmation and contrast from the results. The evaluation designs are independent of each other which means that it is not necessary to finish one before starting the next: they can be carried out simultaneously (Wood et al. 1999).

The initial design for evaluating **APPLIES** considered an *evolutionary multi-method* strategy. However, after the analysis of the first two empirical evaluations (see evaluation #1 and #5 in Tables 3.1 and 3.2), it was found that this strategy would reduce the number of empirical evaluations that could be completed in the time available. Each empirical evaluation required a few months of full-time dedication, from its design to analysis of the results and there were insufficient resources for this. Furthermore, it was difficult to decide which of the suggested changes should be implemented or discarded when the suggestions affected the structure of **APPLIES**. Thus, it was decided to follow a *complementary multi-method* strategy instead. With this design each evaluation was independent, making it possible to conduct multiple evaluations in parallel and to compare results between evaluations before deciding what changes were relevant to **APPLIES**. Field notes were created to record the observations of each evaluation as soon as possible, but the more in-depth analysis took place simultaneously with the preparation of other empirical experiences. When all evaluations were completed and analyzed, the results collected were integrated and compared to answer the evaluation questions.

Evaluations set

Eight empirical evaluations were completed to respond to the evaluation questions. Four of them used a workshop format and included practitioners (Evaluations #1 to #4), while the other four included experts in PLE (Evaluations #5 to #8). The two groups of evaluations are detailed below and further methodological details on the empirical evaluations summarized in this section are available online at the Research Gate project⁷.

- **Workshops (Evaluations #1 to #4).** Workshops were used to collect the opinions of potential **APPLIES** users with regard to the four quality attributes under evaluation: ease of use, content pertinence,

⁷<https://www.researchgate.net/project/APPLIES-framework-for-evaluating-organizations-motivation-and-preparedness-for-adopting-product-LInES>

perceived usefulness and intention to use, once the participants had used the framework in real (see Evaluations #1, #2 and #4) or illustrative cases (see Evaluation #3). In addition, during the workshops participants recommended new functionalities and evaluation factors based on their experience.

Each workshop had at least three stages in which participants: (i) were trained to use **APPLIES**; (ii) used the tool that **APPLIES** provides to evaluate a real or fictitious case; and (iii) answered questions asked by the researcher in which they evaluated **APPLIES** based on their expectations and experience using **APPLIES**.

The people who participated in these evaluations (Evaluation #1 to Evaluation #4) represented the target population for **APPLIES** because: (i) they had basic knowledge of product line engineering; (ii) they had professional experience; and (iii) they might, at some point, be interested in evaluating the convenience of adopting product line engineering. Five of the participants were leaders in software organizations: one in Evaluation #1 and four in Evaluation #2. Also, 32 participants were potential practitioners with professional experience and basic knowledge in product line engineering: 14 of these participated in Evaluation #3 and 18 in Evaluation #4.

Table 3.1 presents the settings of each workshop, the strategies used to collect the data, the number of participants, their profiles, and when the workshop took place. Further details of each evaluation are described below.

- **Evaluation #1. Retrospective evaluation with the CEO of Acople Tecnológico.** Acople Tecnológico is a small Colombian organization with more than seven years of experience in the software sector. Since its foundation, Acople has created software solutions that use biometric devices to address needs such as access control or time recording. The organization has a consolidated customer base and several renowned Colombian organizations have successfully used its applications. Acople Tecnológico began an incremental transition to a product line approach in 2014. Since then, and to date, the organization has transformed its previous applications into a product line of biometric applications. This organization was considered suitable and was selected based on its experience in adopting a product line approach and its willingness to provide access to the information needed during the evaluation.

The CEO that participated in Evaluation #1 was considered suitable because: (i) he had more than 15 years of experience in the IT business; (ii) he actively participated during the transition from a standard software development approach to a product line approach in his organization, and (iii) he knew in detail the conditions of the organization before and after adopting a product line production approach. Details of this experience are available in [Rincon, Mazo & Salinesi \(2018a\)](#).

- **Evaluation #2. A software organization without experience in product line engineering.** Four senior executives from Asesoftware, a medium-sized software development with no experience in product line engineering used **APPLIES** to evaluate the convenience of adopting a PLE approach in their own context.

Asesoftware is a multinational organization with clients in Colombia, Costa Rica, United States and Chile. This organization has more than 25 years in the software services industry and more than 250 employees. Among its services, Asesoftware offers custom software solutions, specialized consulting, data analysis solutions and IT consulting. Since 2010 Asesoftware has been certified with level 5 for

the CMMi-DEV model, and obtained a level 3 for the CMMi-SVC model in 2018⁸. Asesoftware was selected for this evaluation based on its suitability in two aspects: on the one hand, it is a software development organization, which means it is included in the target audience of **APPLIES**; and on the other hand, people from the organization agreed to use **APPLIES** to evaluate the organization's motivation and preparedness to adopt a PLE approach. The objective of this empirical study was to evaluate **APPLIES** in the context of a real-world software organization that has no experience in PLE, in order to collect stakeholders' perceptions regarding **APPLIES** and their recommendations for improving it. Details of this experience are available in Rincon et al. (2019).

- **Evaluation #3. Potential practitioners evaluate a case study using APPLIES.** 14 participants enrolled in a graduate course on software product lines were trained in using **APPLIES** and used it to evaluate a case study prepared beforehand.

The workshop was part of a postgraduate course of *Software Factories and Product Lines* in the *Master of Software Engineering of Universidad de los Andes (Colombia)* during the first semester of 2018. Although the participants were encouraged to take part in the activity, they were informed that their participation would not affect their grade on the course.

To answer these questions, this evaluation had three activities: (i) *Introduction and Contextualization*, (ii) *Use of APPLIES* (ii) *Evaluation of APPLIES*.

i **Introduction and Contextualization.** At the beginning of the activity, the researcher leading the activity (i) presented herself to the participants, (ii) presented the purpose and stages of the activity, and (iii) introduced the case study using handouts with the description. Once the participants read the description, they completed a questionnaire that assessed their understanding about it. An additional discussion was focused on clarifying doubts and incorrect answers from the participants. The researcher also asked the opinions of the participants about the convenience (or not) of adopting PLE in the organization in the case study.

ii **Use of APPLIES.** Participants used an adjusted version of the tool implementing the APPLIES framework to evaluate the case study. This version had spaces to mark unclear statements and was translated to Spanish. We provide the material to the participants in Spanish to avoid misunderstandings due to language barriers.

While participants interacted with **APPLIES**, the researchers were available to clarify doubts, but they did not interfere with participants' activities. Each participant performed his ratings independently.

Once participants completed the evaluation, they sent back to the researchers an email with the resulting file. During this activity, we also had the opportunity of interviewing two participants that finished early of using the framework.

iii **Evaluation of APPLIES.** Two activities were used to collect participant's feedback after they used **APPLIES**: a satisfaction questionnaire and a group discussion. This section presents later details on the strategies used to collect data for evaluating **APPLIES**.

Further details of this experience are available in Rincon, Chavarriaga, Mazo & Salinesi (2018).

- **Evaluation #4. Multi-company evaluation.** 18 participants were trained in a workshop on

⁸<https://asesoftware.com>

how to use **APPLIES**. They then, individually, visited at least one software organization and used **APPLIES** to evaluate the convenience of adopting a product line engineering approach at each organization. Optionally, the participants responded to a satisfaction questionnaire presented later in this chapter. Their participation was voluntary, anonymous, and independent to reduce biases. Participants were master's students in software engineering from *Universidad Eafit (Colombia)* during the second semester of 2018. Participating in the scheduled activities was part of a 24-hour course on *industrialization of software production*. The final qualification of the participants depended exclusively on completion of the requested activities, regardless of the outcome.

A total of nineteen cases were evaluated, since one participant of the 18 participants evaluated two different organizations. The results included organizations working in different market segments, of different sizes and varying years of experience. Seven cases corresponded to organizations whose main activity was different from software development but had a technology area. The remaining 12 cases corresponded to software development organizations. Of these 12 organizations, six were engaged in tailor-made software development with products belonging to various market segments. The remaining six organizations had products with similar domains. One offered IoT solutions in the agronomy domain, the others in biometrics, telemedicine, e-business, cloud computing, and transport domains. Also, two of these organizations offered consulting services.

This evaluation had three activities: *learning about **APPLIES***, *using **APPLIES** to evaluate the convenience of adopting PLE in a software company*, and *evaluating **APPLIES***. The first activity was conducted as a workshop led by the researcher with the participants, while the remaining activities were completed independently by each participant. Further details of this evaluation are available in [Rincon et al. \(2020\)](#).

- i **Learning about **APPLIES****. The researcher leading the assignment (i) introduced herself to the participants, (ii) presented the purpose and stages of the assignment, and (iii) introduced a case study that was used to train people in the use of **APPLIES**. Each participant used the spreadsheet that implements the **APPLIES** framework to evaluate the convenience of adopting a PLE approach in the company that the case study described. While participants interacted with **APPLIES**, the researcher was available to clarify any questions. Finally, the researcher introduced the participants to the remaining activities of the assignment.
- ii **Using **APPLIES** to evaluate the convenience of adopting PLE in a software organization**. Each participant had to evaluate the convenience of adopting the PLE approach in an organization that developed software. This activity was a replica of the first activity. However, the organization's information was not described in a case study. Instead, participants had two weeks to find the organization, collect the information, conduct the assessment using **APPLIES**, analyze the results, and prepare a report.

A version of the spreadsheet-based tool that supports **APPLIES** was available for this activity. This version included instructions for use and had spaces to mark unclear questions.

Each participant sent to the researcher the filled-out version of the spreadsheet and the written report. Reports included information such as the description of the organization evaluated, the data collection methods, the results obtained when using **APPLIES**, and the recommendation they would give when analyzing the information provided by **APPLIES**.

- iii **Evaluating **APPLIES****. Optionally, participants responded to a satisfaction questionnaire avail-

able online. This questionnaire collected data on the participants' perceived usefulness, their intention to use **APPLIES**, their perception of the ease of use of **APPLIES**, and possible improvements. Participation was anonymous and voluntary to reduce response bias. The questionnaire used a 5-point Likert response format from 1 to 5, in which participants expressed their level of agreement. The questions were inspired by Davis (1989) but were modified to fit the purpose of this research. The questionnaire was created in Spanish, as Spanish speakers would use it. This questionnaire also included an open-ended question to collect explanations related to the closed-ended questions and comments on **APPLIES**. The questionnaire and the data that support the findings here reported are available in ⁹.

Evaluations #1 to #4 aimed at collecting evidence to answer the same evaluation questions, but the participants, as well as the characteristics among the evaluations, were different. Evaluations #1 and #2 involved real software organizations where the participants evaluated using **APPLIES** in their own organization. In Evaluation #1 the organization had already created a product line and the CEO used **APPLIES** to evaluate retrospectively the convenience of adopting product line engineering. Conversely, in Evaluation #2, the organization had no previous experience in PLE and in principle, although it was interested in increasing reuse, it had not considered adopting a PLE approach. Regarding participants' knowledge of PLE, the participant in Evaluation #1 already had experience in PLE, participants in Evaluations #3 and #4 were enrolled in a course that introduced product-line related concepts, and in Evaluation #2 the researcher trained the participants on the principles of PLE in one of the workshop sessions.

Participants in Evaluations #1 and #2 knew their organization's information first-hand, so they represented exactly the type of users for whom this research intends to create an evaluation tool. The limitation for both of these evaluations, however, was that they involved only a limited number of people (five in total, only the CEO participated in Evaluation #1, while four organization leaders participated in Evaluation #2). While the number of people involved is not a critical factor in qualitative research, increasing the number of people who interact with **APPLIES** could strengthen the evidence collected to support the findings. Thus, in an effort to increase the number of people that used **APPLIES**, Evaluations #3 and #4 were conducted with graduate students who had professional experience. However, unlike in Evaluations #1 and #2, participants were less informed about the organizations under evaluation because they were acting in a consulting role and did not necessarily have a relationship with the evaluated organizations.

⁹<https://doi.org/10.13140/RG.2.2.22639.87207>

Table 3.1: Summary of the four empirical evaluations (Evaluations #1 to #4) conducted as workshops to evaluate ease of use, perceived usefulness, intention to use, and improvements.

	Id	Evaluation settings	Data collection strategies	Participants' profile	Participants	Date
People from industry	1	Retrospective. Software organization with more than seven years' experience in the software sector. This organization had around three years of experience when the evaluation was conducted.	Direct observation and semi-structured interview, think aloud	CEO from a software organization	1	March 2018
	2	Prospective. Software organization with more than 25 years' experience in the development of custom software solutions, but no experience in product line engineering.	Direct observation, focus group and questionnaire	Four executives who have been working in the organization for more than eight years	4	May 2018
Potential practitioners	3	Participants used APPLIES to evaluate the convenience of adopting product line engineering in a case study prepared beforehand .	Two interviews, a focus group, direct observation, a questionnaire with open-ended and closed-ended questions and the instrument filled out by the participants	Engineers enrolled in a postgraduate course that represent potential users of APPLIES . Although participants were encouraged to participate in the activity, they were informed that their participation would not affect their qualification in the course	14	May 2018
	4	Participants individually visited at least one organization and used APPLIES to evaluate the convenience of adopting product line engineering in the visited organizations.	A questionnaire with open-ended and closed-ended questions and the instrument filled out by the participants		8	August 2018

- **Experts in PLE (Evaluations #5 to #8).** Expert interviews are useful for evaluating and improving the content of an artifact under development to make it correct and relevant to the domain under study (Li & Smidts 2003). Eleven experts participated in the evaluations. They were interviewed separately, with the exception of Evaluation #7, in which Experts #8 and #9 requested to be interviewed at the same time because they work closely together. Seven of the eleven experts are academics whose adoption experience comes from collaborative projects between academia and industry (Experts #1 to #7), while the other four experts are well-known in the product-line community due to their experience and knowledge in PLE adoption (Experts #8 to #11).

Table 3.2 presents an overview of the four evaluations conducted with experts. This table presents for each evaluation: an identification number, a summary of the evaluation setting, the purpose, the data collection strategies, the participants, and the period in which the evaluation took place. Settings and

purpose vary among the four evaluations with experts. Evaluation #7 intended to identify elements that experts with extensive experience in product line engineering adoption take into account when advising organizations interested in adopting this paradigm, while Evaluations #5, #6, and #8 were aimed at evaluating **APPLIES**. In Evaluation #5, experts reviewed the content and also interacted with the tool that implements **APPLIES**, while in Evaluations #6 and #8 the experts had contact only with the content.

Evaluations #5 and #8 had the purpose of evaluating the relevance and understandability of the content that constitutes the assessment models in **APPLIES**. However, the experts had different profiles and the evaluations used two different versions of **APPLIES**. While the experts who participated in Evaluation #5 had mainly academic experience, experts who participated in Evaluation #8 had extensive expertise in accompanying organizations from different industries in the adoption of PLE. Appendix C presents each expert in detail. Further details of each evaluation are described below.

- **Evaluation #5. Review with academic experts.** Initially, four experts were invited to participate in the expert review of **APPLIES**. Once they accepted, an email with a guideline that presents **APPLIES** and a questionnaire to evaluate the conceptual basis of **APPLIES** was sent to them. Two of them sent back the completed questionnaire while the other two did not respond within 30 days. Due to the above, a fifth expert was contacted, who agreed to participate in an interview. Experts #3 and #4 also agreed to participate but only in the interview. In total, five experts participated in the evaluation (Experts #1 to #5). Four were interviewed and one of these also answered the questionnaire sent by email to evaluate the content of **APPLIES**, while another only answered the questionnaire but did not participate in the interview. Of the four experts who were interviewed, two reviewed the content in detail during the interview, and one expert reviewed the content in general but did not go deeper into the details of the content. The interviews were conducted individually, two of them face-to-face and two of them virtually.
- **Evaluation #6. Review of the importance of some evaluation factors.** A list of assessment criteria was provided to Experts #6 and #7. Each expert ranked the criteria according to his opinion of the importance of each criterion to evidence that an organization is prepared to adopt a PLE approach. The possible values for ranking the evaluation criteria were: irrelevant, desirable, important, and very important. The researcher asked the experts to explain their reasons for the classification, and documented these responses in a rating form prepared beforehand for this activity. Each expert was interviewed separately.
- **Evaluation #7. Exploratory evaluation with industry experts.** This evaluation aimed to identify factors that senior experts in PLE consider in the elaboration of well-founded arguments that decision-makers need to initiate an adoption decision. The information was collected from four senior experts in the PLE community, as they have over 20 years of experience advising organizations of different types, markets and sizes (Experts #8 to #11). The experts who participated in this evaluation did not interact with **APPLIES** although the researcher told them about its existence and objective.
- **Evaluation #8. Review with industry experts.** This evaluation was divided into two interviews. Experts #8 and #9 participated in the first interview and only expert #8 participated in the second one. In the first interview, the researcher shared the objective of **APPLIES** with the experts who then made general recommendations regarding the functionalities. In the second interview the researcher presented Expert #8 with the content of the assessment models included in **APPLIES** and collected his suggestions.

The evaluations with experts took place during three periods. The first period was between March and May of 2018 (Evaluation #5); the second period was in September of 2018 during the 22nd International Conference on Software and Systems Product Lines (SPLC) at Gothenburg, Sweden (Evaluations #6 to #8)¹⁰. Finally, in October 2020, a remote interview was conducted as part of Evaluation #7, to clarify some of the comments collected from Expert #10 in 2018.

Table 3.2: Summary of the empirical evaluations conducted with experts (Evaluations #5 to #8).

Id	Evaluation settings	Purpose	Data collection	Participants	Date
5	Five academic experts participated in this evaluation.	Ease of use, content pertinence, perceived usefulness and intention to use	Questionnaires, think aloud, and semi-structured interviews	Experts #1, #2, #3, #4, #5	Between March and May 2018
6	A list of evaluation criteria was provided to Experts #6 and #7. Each expert ranked the criteria according to his opinion on the importance of each criterion to evidence that an organization is prepared to adopt a PLE approach.	Content pertinence	Semi-structured interviews and think aloud	Experts #6 and #7	September 2018
7	Semi-structured interviews with experts who have experience accompanying organizations in adopting product line engineering.	Identify barriers to continuing with an adoption process, factors considered by the experts as fundamental for a successful adoption, factors that denote PLE is a convenient alternative for organizations	Semi-structured interviews	Experts #8, #9, #10 and #11	September 2018 October 2020
8	The researcher presented APPLIES to two experts with wide experience in the adoption of a PLE approach. The experts provided their feedback.	Ease of use, content pertinence, perceived usefulness and intention to use	Semi-structured interview	Experts #8 and #9	September 2018

Data collection strategies and collected evidence

The following strategies served to collect material: direct observation, semi-structured interviews and focus groups, questionnaires, think aloud and documentary analysis.

- **Direct observation.** Observations took place in Evaluations #1, #2 and #3 while participants completed the tasks assigned during the evaluations. The researcher did not interfere with the activities performed by the participants, but she answered questions and made clarifications when necessary. The observations were registered in real time through note-taking and recording of participants' voices.
- **Semi-structured interviews and focus groups.** Semi-structured interviews¹¹ were used in Evaluations

¹⁰The SPLC conference is the main venue for systems and software product line engineering in the world. Key researchers and industrial practitioners around the world attend this event. This event was, therefore, an excellent opportunity to reach world-class industrial experts in the product line community.

¹¹Semi-structured interviews are guided by a pre-established set of questions, but the interviewer can ask for clarifications, go deeper into any response if necessary and ask new questions as new information is learned (Alkin 2011).

#1, #3, #4, #5, #6, and #7, and focus groups¹² were used in evaluations #2 and #3 because several people participated in the evaluation. All interviews and focus groups were audio recorded with the exception of the two interviews conducted in Evaluation #6, in which the experts rated the importance of some factors under evaluation. These interviews were not recorded as they took place during a break of the SPLC conference in 2018 and at that time the researcher did not have access to a recording device. However, to avoid loss of information, the results were recorded on a form and field notes were written to summarize the results of both interviews.

Questions in interviews and focus groups were introduced in the order recommended by Leung (2001) from general questions to more specific and from easy questions to more difficult. Furthermore, open questions that asked for general recommendations were introduced in the final part of the interviews. Also, as recommended by Runeson et al. (2012), major findings were summarized by the researcher before ending the interview or focus group in order to confirm that the interviewee's opinions were properly understood. Table B.13 in Appendix B contains the list of questions asked.

Collected data

Twenty-five audio files were collected. There are more audio files than evaluations because different audios were collected from each evaluation. For example, interviews were sometimes interrupted due to external factors, or the evaluation had different parts with each part recorded separately and resulting in different audio files.

- **Think aloud.** Some participants were instructed to speak out loud while they interpreted the three charts provided by APPLIES that summarize results. These charts are: *alignment with adoption drivers*, *share of selected drivers* and *preparation grid*. The first two charts belong to APPLIES-motivation and the last chart belongs to APPLIES-preparation. Chapter 4 provides details of these charts.

Interpreting the charts requires that the people who interpret are given time to visualize and analyze the data displayed. For this reason, the interpretation was requested only in some evaluations. Specifically, the participant from Evaluation #1 interpreted all three charts; two participants randomly selected from Evaluation #3 interpreted charts related to the organization's motivation, one chart each; one expert from Evaluation #5 interpreted all three charts; another expert from the same evaluation interpreted the two charts resulting from APPLIES-motivation; and another expert interpreted only the chart resulting from APPLIES-preparation. In each case, the question posed to motivate the interpretation was: *How do you interpret this chart?*

The think aloud information was complemented with the interpretations collected from 19 cases reported in written reports (introduced later in this section). In summary, 23 people interpreted the two charts presented by APPLIES-motivation (Chart #1 and Chart #2) and 22 people interpreted the chart resulting from APPLIES-preparation (Chart #3) (Table B.11 presents the details). The analysis of the evidence considers to what extent people who interacted with APPLIES were able to interpret the charts that APPLIES includes.

- **Satisfaction questionnaire with open and closed-ended questions.** This questionnaire was designed to collect information from the participants' on perceived usefulness, their intention to use APPLIES, and

¹²Focus groups are a special form of interview that involves a group of respondents. The moderator has a set of pre-prepared questions and people in the group have valuable information in response to these questions. Participants discuss ideas, issues, perceptions and experiences among themselves in relation to the questions, and each member is free to comment on the opinions expressed by others. The premise behind the focus group method is that free discussions generate new ideas and perceptions because participants stimulate each other (Kumar 1993, Alkin 2011).

possible improvements. In the questionnaire the items used a Likert 5-point response format ranging from 1 to 5, in which participants expressed their level of agreement. The questionnaire also included open-ended questions to collect explanations related to the closed-ended questions, and comments on **APPLIES** to respond to *EQ5: What additions or modifications could improve **APPLIES**?* In addition, the questionnaire collected demographic information from the participants, such as their current job (open-ended question) and their professional experience (closed-ended question with four options: less than one year, between one and three years, more than three years but less than five years, and five years or more). The questionnaire was created in Spanish, as it was aimed at Spanish speakers.

Perceived usefulness was evaluated with four items, while intention to use was evaluated with two items. Table B.5 in Appendix B presents the resulting items, as well as the labels assigned for the lowest and highest value of the response format, the evaluations in which the item was used, and the number of responses collected from each evaluation.

Collected data

Twenty-five people responded to the satisfaction questionnaire. Evaluation #1 and Evaluation #2 had one response each, Evaluation #3 had 14 responses and Evaluation #4 had 9 responses (see Table B.5). Appendix B presents a table of anonymous data records with the participants' responses, which were collected as follows:

- **Evaluation #1.** Items from Table B.5 were asked as part of the interview with the CEO from the software organization.
- **Evaluation #2.** Four of the organization's leaders participated in Evaluation #2, but only one responded to the first questionnaire used in this evaluation. The last activity planned for participants in the final workshop session was to respond individually to an online questionnaire containing the items from Table B.5. However, due to time constraints, the activity was not carried out during the workshop. The link to the questionnaire was mailed to all four participants, but only the leader of architecture completed it. Although all four participants were informed that the questionnaire would be sent by email, in the initial planning their participation had been requested for only two workshop sessions, so they did not feel pressured to complete the final feedback.
- **Evaluation #3.** Seventeen of the 21 people enrolled in the course participated in Evaluation #3. In the final part of the workshop session 17 participants responded individually to an online questionnaire containing the items from Table B.5. The participation was anonymous and voluntary to reduce response bias. During the analysis of the data it was found that three of the 17 participants had less than one year of professional experience and were not working at the time of the workshop. These three responses were excluded from the analysis, as the aim was to collect the opinions of real practitioners. Thus, only 14 of the 17 responses were analyzed.
- **Evaluation #4.** Nine of the 18 people enrolled in the course responded to an online satisfaction questionnaire that unified the items presented in Tables B.5 and B.6. The questionnaire used in this evaluation was the only one that included questions that evaluated ease of use (presented in Table B.6), because in this evaluation the participants used **APPLIES** independently to evaluate the convenience of adopting product line engineering in at least one software organization, and because there was no other space for discussion of ease of use of **APPLIES** between the participants and the researcher during this evaluation. (In the other evaluations, this information was collected qualitatively with open-ended questions.) Participation in the satisfaction questionnaire was anonymous, voluntary and

independent. This could explain why the number of responses received was lower than the number of people who participated in the activities that were graded as part of the postgraduate course in which this evaluation took place.

- **Documentary analysis.** The set of evaluations produced the following documents:
 - **Questionnaire that evaluated content, as part of Evaluation #5.** Experts #1 and #2 completed the questionnaire that collected information on the understandability and pertinence of the assessment models.
 - **Spreadsheets that implemented APPLIES.** 14 spreadsheets that consolidated statements marked as unclear collected in Evaluation #3, and 19 collected in Evaluation #4.
 - **Written reports.** 18 written reports collected from Evaluation #4. A participant who evaluated two organizations reported the results in the same written report. In these written reports, the participants collected information using at least one data collection method such as interviews, focus groups, surveys, or documentary review. In three cases the participants carried out the evaluation themselves as they worked in the organization they were evaluating and had the information that **APPLIES** requested. Finally, in six cases the participants filled out the instrument together with personnel from the organization.

While using the charts included in **APPLIES** was not explicitly requested in the written reports, their use in the delivered reports served to help analyze the extent to which the charts were useful and how well participants were able to interpret the charts they used. Also, the written reports were analyzed to identify patterns among the recommendations of the participants, the characteristics of the organizations under analysis, and the results of **APPLIES**.

- **Transcripts and text files that consolidated the open-ended questions.** Data collected through think aloud, interviews, and focus groups were recorded. These recordings were then transcribed because a written format enabled more detailed study of the responses. The transcriptions were prepared using MAXQDA¹³, a Computer-Assisted Qualitative Data Analysis Software that assists researchers in transcribing, coding, and later analyzing qualitative data. Transcripts were prepared in the same language (either English or Spanish) in which the interviews/focus groups were conducted, in order to maintain the meaning of the original message. Transcriptions were prepared by the researcher using an “intelligent transcription” strategy, *i.e.*, a strategy that aims to improve legibility of the text by *e.g.*, by solving grammatical errors, removing irrelevant words or sentences and adding personal pronouns or articles omitted in natural speech. Intelligent transcriptions are useful for academic purposes where legibility and clarity are fundamental (Bailey 2008).
- **Field notes.** After each evaluation, field notes were written up to document the development of the empirical experience, based on the researcher’s observations¹⁴. Field notes were useful to document the general settings of the experience, emerging questions resulting from the evaluation, and elements to improve in subsequent evaluations.

¹³MAXQDA is software for qualitative text and content analysis. For further information please refer to <http://www.maxqda.com/>

¹⁴Field notes are the written account of what a researcher hears, sees, experiences, and thinks about during the execution of a qualitative study (Bogdan & Biklen 2007)

3.2.2.3 Analyze the evidence

The material collected in each evaluation was analyzed independently, with the aim of the researcher becoming familiar with each evaluation as a stand-alone entity which, in turn, facilitated cross-evaluation comparisons. The following considerations were taken into account when analyzing the material collected:

- The close-ended questions of the satisfaction questionnaire were analyzed using descriptive statistics. The collected spreadsheets were reviewed to identify items marked as “unclear”.
- Documents collected and produced (field notes, transcripts, written reports, responses to open questions) were organized in MAXQDA. These files were coded and analyzed one at a time using *direct content analysis*. This technique uses a systematic process for coding and analyzing material to describe its meaning (Hsieh & Shannon 2005). Content analysis seeks to provide knowledge and understanding of the phenomenon under study by extracting categories of data (Hsieh & Shannon 2005). Direct analysis is a type of content analysis that combines deductive and inductive principles: deductive, because there is a list of preconceived codes or categories derived from the relevant theory, previous research or literature; inductive, because the researcher refines this list as the data analysis progresses (Hsieh & Shannon 2005).

The data analysis phase started with an arbitrary list of four codes (i.e. “Framework suggestions”, “New adoption drivers”, “New assessment criteria”, “Evaluation results”). This list was updated incrementally as the collected data from the different experiences were analyzed.

Once the written texts were completely coded, each file was read again to verify the consistency between fragments and codes. Additionally, when code modifications affected fragments that had already been coded, these were rechecked to ensure that the assigned codes were still consistent with the text. In this process, the MAXQDA tool was handy because it offers functionalities to merge, eliminate, divide, or reorganize the code hierarchy. A codebook was built along with the coding process, which compiles a list of codes used during the coding process and their meaning. This information is useful to maintain consistency in the coding process. Appendix D presents details about the procedure used for coding and analyzing the data.

3.2.2.4 Integrate the evidence

This was the final stage of the evaluation phase, and served to synthesize and holistically interpret the data collected to answer the evaluation questions. The evaluation questions guided the cross-analysis so evidence from various sources were used to analyze each question.

The stage included the following activities to cross-analyze the results, find contradictions and similarities; and triangulate the results:

- **Processing.** This activity integrated the material collected in the different evaluations.
 - Responses to the close-ended questions from the satisfaction questionnaire (**source:** Evaluations #1, #2, #3 and #4)
 - Comments on defects in the content of the motivation assessment model and the preparation assessment model (**source:** Evaluations #1, #2, #3, #4, #5, and #8)
 - Comments on the relevance of the content (**source:** Evaluations #2, #5, #6, #7, #8)
 - Interpretation of the charts (**source:** Evaluations #1, #3, #4 and #5).

Table 3.3: Collected data by evaluation question

Dimension of analysis	Sources					
	Transcriptions	Satisfaction Questionnaire - close ended questions	Open questions	Written reports	Others	
EQ1	Ease of use - response format	1,2,3				Two questionnaires collected in Evaluation #5. Two spreadsheets that consolidate items marked as unclear in the responses collected in Evaluations #3 and #4.
	Ease of use - charts	1,3,5,8	9 responses collected in Evaluation #4	4	4	
	Ease of use - charts interpretation	1,3,5		4	4	
	Ease of use - tool	1,2		3,4		
	Ease of use - content understandability	1,2,3,5		3,4		
EQ2	Content pertinence	1,2,3,5,7,8		3	4	Field note from Evaluation #6 and importance rating from Evaluation #6
EQ3	Perceived usefulness	1,2,3,5,8	25 responses collected in Evaluations #1, #2, #3 and #4	3,4		
EQ4	Intention to use	1,2,3,5,8	25 responses collected in Evaluations #1, #2, #3 and #4	3,4		
EQ5	Improvements	1,2,3,5,8		3,4		

- **Re-coding.** The coded texts from the whole set of evaluations were analyzed again to group similar themes and identify contradictions.
- **Analysis.** The evidence collected was analyzed using a bottom-up approach: from the data to the themes and from the themes to the findings. The findings were then grouped together to respond each research question.

Table 3.3 shows the type of material and the evaluation from which this material was collected for each question. As can be seen in the table, each research question grouped evidence from at least two different evaluations and used different types of evidence because of the multi-method strategy. For example, the material for evaluating perceived usefulness (see question EQ3) consisted of transcripts from Evaluations #1, #2, #3, #5 and #8 and the responses to closed and open-ended questions from the satisfaction questionnaire.

The multi-method approach applied in this dissertation, synthesized the evidence using a narrative synthesis technique (Rodgers et al. 2009). According to this technique, evidence is arranged and interpreted with a narrative. Thus, each finding was analyzed narratively and related to the evaluation and the source of evidence providing the facts. Where necessary, data sources that suggested contradictory evidence were also reported.

3.3 Threats to validity

Although it is widely recognized that in qualitative research the researcher will inevitably influence the interpretation of the results (Steinke 2004), the following strategies were used to reduce threats to validity and to facilitate the replication of the steps followed during this research:

- **Internal validity:** This is affected when a researcher has not adequately controlled interfering variables or was not aware of them at all. This lack of control can influence the outcomes of the evaluation, which can lead to false cause/effect relationships.
 - *Planning and documentation to avoid inconsistencies in execution and analysis.* The empirical evaluations were designed before they were carried out, in line with the guidelines proposed by

well-known authors such as Kitchenham et al. (2007), Easterbrook et al. (2008), Yin (2008), Runeson et al. (2012), Wohlin et al. (2012). These designs were recorded in protocols that synthesized decisions previously discussed with the supervisors of this thesis. In addition, guidelines were defined to process the collected transcripts¹⁵ and, as recommended by Saldaña (2013), a codebook was created with definitions to maintain consistency during the coding process.

- *Triangulation to avoid the effects of interpretation from a single data source.* Researchers use triangulation to reduce bias in the data and the likelihood of misinterpretation by checking the findings against various data sources and perspectives (Denzin 1970). There are four types of triangulation in qualitative research: *by research method, by theory, by using different researchers, and by respondents or informants* (Denzin 1970). This research mainly considers two types of triangulation, *by research method and by respondents*:

- * Regarding the *research method*, all the empirical experiences combined more than one technique for collecting the data such as direct observation, semi-structured interviews, focus groups, questionnaires or documentary analysis.
- * Regarding the *respondents*, this research followed a qualitative approach and therefore it was unknown beforehand how much data would be needed to evaluate the proposal. However, a question that guided the whole design was: *Which cases should be selected?* Based on this question, the research aimed to collect the points of view of four interest groups: product line adoption experts, organizations with no experience in PLE, organizations with product line experience, and engineers with basic knowledge in product line engineering who might need to evaluate the convenience of adopting PLE in their organizations. The evaluation phase of this research thus included participants who had different experiences, providing multiple dimensions from which to explore the results. This design also increased the generalization of the findings by considering groups of interest that were representative to the potential population of **APPLIES** users.

The data-gathering process ended when each interest group for **APPLIES** had participated in at least one evaluation. However, more replicas to increase the external validity of the results may be necessary.

- *Subject-expectancy effect.* This bias implies that those who expect a certain outcome behave in a way that ensures it (Ko et al. 2013). The results from the students who participated in Evaluations #3 and #4 may pose validity concerns. To mitigate this risk, in Evaluation #3 the researcher had no authority over the participants. During Evaluation #3, while participants interacted with **APPLIES**, the researcher was available to clarify doubts, but she did not interfere with participants' activities. Each participant performed his ratings independently and once participants completed the evaluation, they sent back to the researcher an email with the resulting file. With regard to Evaluation #4, no specific outcomes were expected as the evaluation did not aim to favorably compare **APPLIES** to other proposals, and therefore there were no correct or incorrect answers. Whether the participants were for or against adopting a product line engineering approach was irrelevant to the results obtained after using **APPLIES** in organizations. These results were useful for the analysis and did not affect the grades of the participants in the course. The only requirement for achieving a maximum grade was to complete the assignment. However, because of the inherent power imbalance between faculty and

¹⁵ Available online at <http://doi.org/10.13140/RG.2.2.30403.66086/1>

students, and even though their grades would not be affected, there still remained a real possibility that participants may have evaluated **APPLIES** positively in a misguided attempt to be “nice” to their teacher. In order to reduce this possible bias, the questionnaire that evaluated **APPLIES** was made optional and anonymous. Unfortunately, a side-effect of this decision was that only nine of the 18 participants in Evaluation #4 answered the questionnaire, which meant that the amount of data collected to evaluate **APPLIES** was less than expected.

- *Ignorance of the participants of other alternatives similar to **APPLIES**.* This bias was not considered an issue in any of the evaluations because the purpose was to evaluate **APPLIES** itself and not to compare **APPLIES** to other solutions.
- *Quality of the responses provided in **APPLIES**.* In Evaluations #1 and #2 the participants evaluated their own organization so it is assumed that the answers corresponded to the reality of each organization. In Evaluation #3 the understandability of the material was achieved by clearing up any misunderstandings during the workshop session. Furthermore, to mitigate the risk of misunderstanding the case study: (i) participants completed a questionnaire that assessed their understanding of the case before using **APPLIES** (ii) these responses were used in a plenary session to emphasise points where low comprehension levels were found; and (iii) a member of the research team played the role of expert to answer participants’ questions. Additionally, the material was written in Spanish to avoid misunderstanding due to lack of proficiency in the English language. Finally, since in Evaluation #4 the participants carried out the evaluation independently, the researchers cannot be sure that the responses collected in each evaluation represent the actual state of the organizations evaluated.
- **External validity.** All evaluations used convenience sampling due to the availability of possible respondents. This resulted in selection bias and limits the generalization of the findings (Given 2008). In an effort to triangulate the results and improve their generalization, the evaluations included people with different profiles. However, it is possible that the findings of the evaluation would vary if different people had been consulted as the context, region, country and experience of a person may influence their opinions. Another aspect that could limit the external validity is that in the workshop-type evaluations, the participants only belonged to the software development sector. It would be very interesting to include in the next evaluation cycles people with experience in cyber-physical systems as there are multiple cases of successful adoption of product line engineering in this sector and people with this kind of experience may have other insights that were not detected in the evaluation.
- **Construct validity.** This refers to ensuring the correctness of the measures involved in the investigation, the relevance of the concepts used and a proper chain of evidence.

The synthesis process is inextricably linked to the researchers, and therefore there is always a risk that the factors identified in this research are not valid representations of experts’ views but are rather a reflection of the researchers’ own views. For example, the emerging findings from the synthesis that seemed most important were chosen, at least in part, subjectively. This threat to construct validity is inherent within all types of qualitative research where a researcher takes an interpretive theoretical stance. The following strategies were incorporated into the evaluation methodology in order to increase construct validity.

- *Minimize the scope for interpretation:* each concept was explicitly re-checked at the end of the analysis to ensure that its existence was justified by statements from the source data. Also, during interviews and focus groups the researcher paraphrased and summarized the answers given by the participant in order to confirm that the opinions had been correctly understood (Runeson et al. 2012).

- *Traceability between the source and the analysis to avoid misunderstandings between the collected data and reality.* A line-by-line analysis was used to ensure that all sources of data were explicitly considered to determine whether they were relevant to the research questions. Then, extracts from the data sources that justified the reasoning behind the resulting analysis were always kept. In this way, the link between the data source and the corresponding interpretation is available for verification; and since all findings are linked to specific evidence (either a quote, a questionnaire response, etc.), it is possible to provide a grounding for the reported results and attribute them to the collected data.
 - *Test-retest to reduce bias in the analysis process.* This strategy involves repeating (after an appropriate time-frame) some or all the actions that were taken in the analysis to compare the outcomes (Kitchenham et al. 2015). This strategy was used during the transcript and coding process to control for subjectivity and bias. For example, a week or more passed between completion of the first version of the transcripts and the second revision and adjustment. Regarding the coding of the material, a week or more also passed between the initial coding of the transcripts and the revision of the coding, before proceeding with the analysis and interpretation of the results. Finally, whenever possible, supervisors randomly reviewed coded data segments to evaluate the relevance of the assigned codes.
 - *Overconfidence bias:* extracting expert opinion is a qualitative method that requires a degree of subjectivity and implies the problem of relying on informal evidence that may be influenced by personal opinion (Kitchenham et al. 2007). Tversky & Kahneman (2007) explain that experts' revision is subject to what is known as overconfidence bias. Overconfidence bias is a tendency in which a person's confidence in his or her judgments is greater than the objective accuracy of those judgments. To mitigate this threat, in Evaluations #5, #6, #7 and #8 the strategy proposed by Chibbet et al. was followed, in which the experts were asked to justify their responses as the interviews progressed (Chibbet et al. , cited by Li & Smidts (2003)).
- **Data collection tool: satisfaction questionnaire.** Questionnaires should have items logically interrelated to elicit information about the constructs under analysis, without defects that would distort the information. For this reason, the questionnaire introduced in Table B.5 was evaluated for internal consistency by computing the Cronbach's alpha test. Cronbach's alpha is the most widely used measure of reliability and describes internal validity (Hinkin 1998), which is how much each measured element correlates to each other, or the overall consistency of the questionnaire (Cronbach 1951). Cronbach's alpha test was chosen because it is a common practice when multiple-item measures of a concept or construct are employed (Bandura 2006). Cronbach's alpha test is easier to use in comparison to other estimates such as the test-retest reliability estimates as it only requires one test administration (Tavakol & Dennick 2011). The result of the Cronbach's alpha test is affected by the test length and response format but in particular, the satisfaction questionnaire had the conditions needed to apply this test: more than two options in the response format and more than three questions (Hinkin 1998).

The questionnaire to evaluate the **perceived usefulness** and **intention to use** (see Table B.5) has a Cronbach's alpha of 0.73 and the questionnaire to evaluate the **ease of use** has a Cronbach's alpha of 0.83. Both values were calculated using SPSS 25.0 for Windows.

An acceptable value for Cronbach alpha is 0.7 but a minimum of 0.8 is the most desirable value (Hinkin 1998). Therefore, **the internal consistency of both questionnaires is acceptable and the above conclusions are valid**, but the **questionnaire presented in Table B.5 needs adjustments to improve its reliability to increase Cronbach's alpha** from the acceptable value to the minimum desirable value of 0.8.

There are two ways to improve Cronbach's alpha. One way is to eliminate elements, since the instrument could have, for example, negative correlations that reduce its reliability. The second way is to increase the number of items, as the calculation of the alpha is affected by the length of the questionnaire (Hinkin 1998).

SPSS has a feature to evaluate the Cronbach's alpha increment if items are removed from the questionnaire. If the Cronbach's alpha increases through the deletion of an item, the item should be dropped because it is inconsistent with the instrument. In the case of the instrument designed to evaluate the perceived usefulness and intention to use eliminating elements does not increase the Cronbach's alpha value to reach the desired minimum of 0.8 (Table B.10 shows the result of this analysis). Therefore, instead of suppressing items, the number of items in the questionnaire should be increased in subsequent evaluations to later evaluate the reliability of the instrument again.

3.4 Summary of Chapter 3: Methodological details

Chapter 3 presents the methodological details of how the research was carried out to satisfy the intended objectives. It is divided into three main sections: the research methodology, the phases of the research, and the strategies used to limit threats to the validity of the research.

Overall, the research follows a Design Science Research (DSR) methodology where the objective is to create a purposeful artifact that can be used in a real context while following a rigorous process. The first section details how the research is aligned to DSR principles and how the six activities of DSR identified by Peffers et al. (2007) are followed.

The second section divides the phases of the research into two main parts: *construction* and *evaluation*. The *construction* phase aims to (i) find and analyze literature that could serve as input to the design of **APPLIES**, the framework proposed to enable newcomers to PLE to evaluate the convenience or otherwise of adopting a PLE approach, and (ii) develop the **APPLIES** framework itself. This chapter details the methodology used for the analysis of the literature while Chapter 4 explains how the **APPLIES** framework is designed.

Detailed description is provided on how the analysis of the literature is carried out to provide input for the content of **APPLIES**, including the search strategies used and exclusion criteria developed. In the end, forty articles are reviewed in detail with the aims of identifying key factors that motivate organizations to adopt a PLE approach and key factors to evaluate the preparedness of organizations. Data analysis is carried out using thematic analysis which includes coding the material, identifying themes and constructing thematic networks.

The *evaluation* phase aims to evaluate ease of use, content pertinence, perceived usefulness, and intention to use of the proposed framework and to collect suggestions for improving **APPLIES**. The chapter introduces five evaluation questions that guide the empirical evaluation and explains the steps followed to find, analyze, and integrate the collected evidence.

This phase uses a complementary multi-method design in which the proposed framework is independently evaluated by respondents of different profiles through eight evaluation experiences, seeking confirmation and contrast from the results. Both the data collection methods and the respondents are triangulated to reduce the effects of interpretation and increase reliability. On the one hand, each of the empirical evaluations uses more than one data collection technique, such as direct observation, questionnaires, think aloud during the interpretation of charts, documentary analysis, semi-structured interviews, and focus groups. On the other hand, with regard to the respondents, four of the eight empirical evaluations included practitioners (Evaluations #1 to #4), and the other four included experts in PLE (Evaluations #5 to #8).

The collected material is first analyzed independently and then synthesized to find the overall results. Data collected from close-ended questions is analyzed using descriptive statistics, while documents such as field notes, transcripts, written reports, and responses to open questions are analyzed using direct content analysis, a technique used in qualitative research for coding and analyzing material to identify its meaning.

The final section describes the range of strategies used to reduce threats to validity. For example, to increase internal validity, the empirical evaluations are planned with a protocol, and the data collection methods and respondents are triangulated. With regard to external validity, while recognizing that the generalization of the findings is limited by the use of convenience sampling, the evaluations include people with different profiles in an effort to improve the possibility of generalization and reduce selection bias. The construct validity of the evaluation of the framework is also addressed by using strategies to ensure, for example, traceability between sources and analysis, minimizing the scope for interpretation by the respondents and test-retest to reduce bias during the analysis process. The threat to the validity of one particular data collection tool, the satisfaction questionnaire, was also considered and while it meets the minimum requirements of Cronbach alpha, it would be useful to improve this instrument in the future.

The remainder of the *construction* phase, i.e., the development of the **APPLIES** framework is presented in the following chapter.

CHAPTER 4

The **APPLIES** framework

The perceived gap between the need to evaluate the convenience of adopting a product line engineering approach and the four limitations identified in existing product line engineering approaches triggered interest in proposing an approach to assist newcomers to evaluate the convenience of adopting a PLE approach. This approach is entitled **APPLIES** which stands for framework for evaluAting organization's motivation and PPreparation for adoPting product LInES.

This chapter presents the **APPLIES** framework. The first section outlines an overview and the functional and non-functional requirements that guided its development. The second section presents the structure of **APPLIES**, introducing its three levels. Finally, the third section explains the scope and limitations of **APPLIES**.

4.1 Generalities

4.1.1 Context

APPLIES is a qualitative evaluation framework that assists newcomers in evaluating the convenience of adopting a PLE approach in their own cases. According to the Oxford Dictionary definition, something is convenient when it is useful and can make things easier or quicker¹.

In terms of the *innovation decision process* introduced in Chapter 1, it could be said that it is convenient to adopt a PLE approach if such an adoption is the best possible course of action for an organization. However, the question *would PLE be convenient for a given organization?* is too difficult to answer for newcomers, as this construct is not easily operationalized in terms of just one observable behavior or question.

This research assumes that the term “convenience”, in the context of an organization’s innovation decision process, can be broken down into two constructs: **motivation** and **preparedness** (see Figure 4.1). This deconstruction is based on the two activities included in the *initiation* stage of the innovation decision process (see Chapter 1): *agenda-setting* which corresponds to identifying *motivation*,² and *matching* to evaluate *preparedness*³.

In addition, previous studies have reported that motivation and preparedness are two dimensions that influence the effectiveness of organizations when intending to adopt technological innovations (Iacovou et al. 1995, Gemino & Mackay 2006, Armenakis et al. 1993). For example, Armenakis et al. (1993) proposed two key

¹source: Oxford Dictionary

²According to the Oxford Dictionary definition, the word *motivation* can be understood as the reason why somebody does something or behaves in a particular way

³According to the Oxford Dictionary definition *preparedness* is the state of being ready or willing to do something

components to achieve change readiness: (i) the belief that the change is needed, which means that there is motivation to perform the change; and (ii) the belief that the individual and the organization have the capacity to undertake the change, which means that they are prepared to do it.

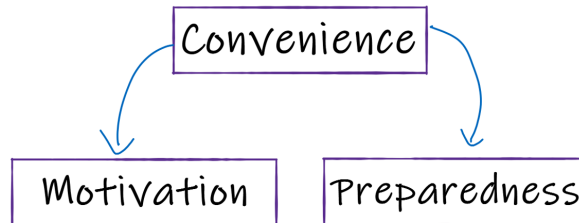


Figure 4.1: The constructs that **APPLIES** considers in evaluating the convenience of adopting a product line engineering approach: motivation and preparedness

4.1.2 Requirements

Functional requirements

- **[FR1-Motivation]. Assist people in organizations to identify what motivates them to consider adopting a product line engineering approach.**

Rationale. If motivational forces are not present, the transition towards a product line approach should not start, regardless of the overall preparedness for this change (Cohen 2002, Kalender et al. 2013). Indeed, motivation is fundamental to the success of any organizational change (Armenakis et al. 1993). People tend to react negatively to change if they do not understand the reasons that justify a need for change. This, in turn, can lead to a lack of staff motivation, low allocation of resources and low organizational support (Iacovou et al. 1995, Kotter & Cohen 2002). On the contrary, when people understand what is driving the change, they are more likely to commit to it (Ackerman-Anderson & Anderson 2010).

- **[FR2-Preparation] Provide an overview of factors that influence positively or negatively organizations' preparedness for adopting PLE.**

Rationale. Adopting a PLE approach implies implementing changes in business, processes and organizational practices, which go far beyond technical considerations (Jones & Northrop 2010). In the same way as people have to go through fitness training before they can run a marathon, organizations and teams must carefully evaluate their current situation before they adopt a PLE approach (Cohen 2002, Böckle et al. 2002). Several authors encourage an evaluation of the preparedness of an organization, before introducing any organizational change (Armenakis et al. 1993, Holt et al. 2007, Kotter & Cohen 2002). According to Northrop (2004), an organization that cannot overcome the barriers entailed in adopting a PLE approach will not succeed in carrying out the adoption. This could happen because a lack of preparation before carrying out the adoption implies that there will be more challenges during the implementation, which increases the likelihood of failure (Razmi et al. 2009).

An overview of preparedness can serve as a comprehensive snapshot of an organization's existing strengths and weaknesses, and a basis to focus resources where they are most needed. Furthermore this information can be useful as a starting point for developing action plans that will help make an organization more capable of achieving success with the adoption.

Non functional requirements

- **[NFR1-Quick evaluation] The evaluation using **APPLIES** should be easy to complete and**

should provide results as quickly as possible.

Rationale. Business issues should be evaluated as quickly as possible because people who know the organization’s business goals, products and market requirements tend to work on a tight schedule (Fritsch & Hahn 2004).

- [NFR2-Systematic] **APPLIES** should contribute towards mitigating subjectivity in the decision-making process by providing guides and tools that assist people to conduct the evaluation.

Rationale. An adoption decision requires that people form either a favorable or unfavorable attitude toward the innovation (Rogers 1983). Without a systematic frame or reference, people could miss analyzing important factors and end up making a decision based on their own personal or cultural biases.

4.1.3 Users

APPLIES considers two types of users:

- Managers who are considering initiating a product line engineering approach in their organizations. These people have an interest in the results of adopting a product line.
- Anyone who needs information to advise people at management levels regarding a potential adoption of a PLE approach.

In both cases, users should have at least some knowledge of product-line related concepts such as benefits, drawbacks, and the main characteristics of this production approach.

4.2 Structure overview

APPLIES consists of three levels: *Conceptualization*, *Operationalization* and *Implementation* as explained in Figure 4.2 and presented in detail in the remainder of this section.

The *Conceptualization* level provides the theoretical basis for **APPLIES**. The *Operationalization* level makes the evaluation tangible, linking to the theoretical basis. Finally, the *Implementation* level provides the support that users require to provide inputs to the **APPLIES** framework and obtain the results. In addition, each of the levels mentioned above consists of two articulated components that evaluate an organization’s motivation and preparedness for adopting product line engineering. The first component is called **APPLIES-motivation** and the second component is called **APPLIES-preparation**.

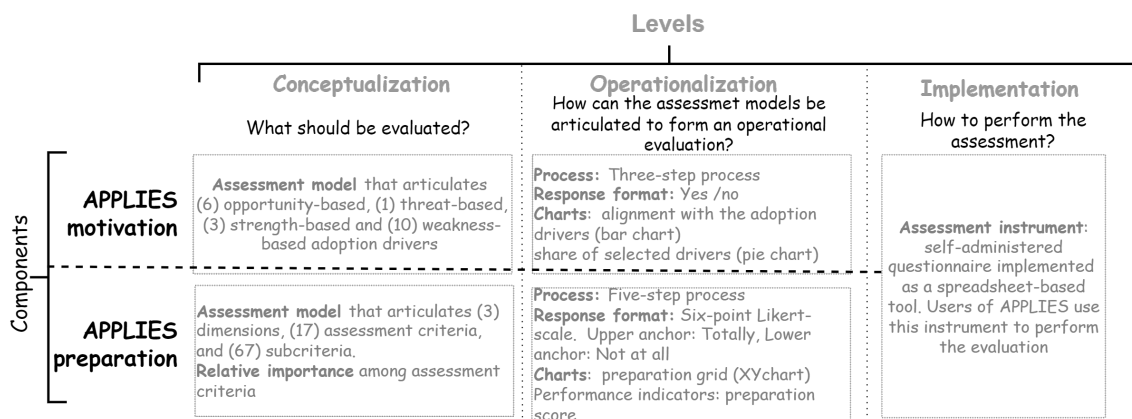


Figure 4.2: Overview of the structure of **APPLIES**. Levels: Conceptualization, Operationalization and Implementation. Components: **APPLIES-motivation** and **APPLIES-preparation**

- **APPLIES-motivation**: **APPLIES** examines the component of motivation to satisfy Requirement FR1. This component seeks to identify the degree of coincidence between the organization's situation and the drivers of product line adoption identified from experiences in the industry. To this end, **APPLIES-motivation** provides information that can help to identify whether a product line could be a solution to tackle an organization's threats, take advantage of its opportunities, strengthen its weaknesses or boost its strengths.
- **APPLIES-preparation**: evaluates to what extent an organization is prepared to transit towards a product line approach and helps users to identify points where particular attention is necessary. Hence, **APPLIES-preparation** aims to answer the question: *to what extent is the organization prepared to adopt a product line production approach?* **APPLIES** examines this component to satisfy Requirement FR2.

4.2.1 Conceptualization

The *Conceptualization* level provides the conceptual basis that defines *what should be evaluated?* in terms of an organization's motivation and preparedness for adopting a PLE approach. In particular, two assessment models drawn from the thematic analysis of related literature introduced in Section 3.2.1 constitute this level: the *motivation assessment model* and the *preparation assessment model*. Both assessment models break down the factors to be evaluated hierarchically until reaching the lowest levels, called *statements*. Users evaluate these statements as they collect information on agreement, preference, or the frequency of something.

All statements are worded affirmatively, and in the same direction. This means that the assessment models avoid reverse worded statements or negative statements completely, as this could confuse respondents making it difficult, for example, to identify whether people understood the statement correctly or if they missed the reversing of wording (Weijters et al. 2013). The two assessment models are available in Appendix B.2 and further details of each are provided below.

4.2.1.1 Motivation assessment model

The *motivation assessment model* provides the conceptual basis of **APPLIES-motivation** and consists of a set of factors that have motivated organizations to adopt a PLE approach in the past. For instance, the organization Dialect adopted a PLE approach due to their economic difficulty to derive new products (Staples & Hill 2004), while repeated maintenance tasks and the management of an uncontrolled set of product parts triggered the adoption in organizations like Engenio and FISCAN (Hetrick et al. 2006, Li & Chang 2009). There are also other triggers, for instance, Salion adopted a product line approach because they needed to deliver customized products quickly in order to survive (Clements & Northrop 2002).

The *motivation assessment model* includes 20 concrete signals, henceforth referred to as *adoption drivers*, which indicate that a PLE approach could be useful for an organization. Most of these adoption drivers are signals reported by organizations with experience in adopting product lines. Adoption drivers were classified according to a SWOT structure (Hill & Westbrook 1997) of strength-based drivers, weakness-based drivers, opportunity-based drivers and threat-based drivers. The category in which each driver was placed depended on whether the driver was considered a strength, weakness, opportunity or threat to organizations. For example, if an organization retains its customers as a result of the variability of its products, then the organization has a strength that could be exploited by adopting a PLE approach. On the other hand, if an organization needs to repeat maintenance work for each customer, then the organization has a weakness that could affect its productivity. In turn, this weakness could be addressed adopting a PLE approach. Figure 4.3 presents an example of two of the adoption drivers and Table B.3 in Appendix B presents the complete set of adoption drivers included in **APPLIES**.



Figure 4.3: Example of two adoption drivers that constitute the *motivation assessment model*

4.2.1.2 Preparation assessment model

The *preparation assessment model* provides the conceptual basis of **APPLIES-preparation**. This part of the framework gathers key factors found in the literature for evaluating to what extent current and future organizational practices may encourage or impede the adoption of a PLE approach. These factors are operationalized into a hierarchy of dimensions, assessment criteria and statements. Figure 4.4 presents an extract of this assessment model and Table B.4 in Appendix B presents the complete model.

Subcriteria	Assessment criteria	Dimensions
Lower level of the hierarchy	Middle level of the hierarchy	Upper level of the hierarchy
Statements that users rate on a scale between “completely disagree” and “completely agree”	Factors that could encourage or restrain a product line adoption in an organization.	Perspectives of analysis from which APPLIES-preparation assesses the level of preparedness of an organization.
Example	Each assessment criteria has one or more subcriteria.	Dimensions of analysis
<i>“Relevant stakeholders will support the initiative to explore a product line solution”</i>	Example	Operational
	Domain knowledge	Technical
	Commitment of the managers	Economic

Figure 4.4: Example of the levels of hierarchy that constitute the *preparation assessment model*

At the upper level of the hierarchy, dimensions are the perspectives of analysis from which **APPLIES-preparation** evaluates the preparedness of an organization, i.e., *operational*, *technical* and *economic*. The operational dimension includes criteria for evaluating to what extent the product line approach fits in with the organizations’ culture, processes, or practices. The technical dimension includes criteria for evaluating to what extent the organization has the technical capability to transition to a product line approach. The economic dimension includes criteria for evaluating to what extent the associated cost and benefits would materialize if a product line approach were adopted.

At the middle-level, each assessment criterion is a signal that **APPLIES** uses to determine to what extent the organization is prepared to adopt a product line production approach. The *domain knowledge*, the *managers’ commitment* or the *potential products of the product line* are some of those assessment criteria. Assessment criteria may be internal or external. Internal criteria are those over which the organization has some influence. For example, *domain knowledge*, *managers’ commitment* or *potential products of the product line*, whereas external criteria are those factors over which the organization has no control, for example *market potential*.

Tertile	Score	Remarks
T1	3 - Very important	$\geq 66.66\%$ max citations ⁴
T2	2 - Important	$\geq 33.33\%$ and $< 66.66\%$ max citations
T3	1 - Desirable	$< 33.33\%$

Table 4.1: Scoring system to calculate the suggested importance value

Finally, at the lower level of the preparation assessment model, the statements, also referenced as statements, describe information that users rate to evaluate the organization's preparedness. For example, the following is a statement that belongs to the criterion **commitment of key actors**: *Relevant stakeholders will support the initiative to explore a product line solution.*

The *preparation assessment model* also defines a number between 1 and 3 for each assessment criterion. Possible values are *very important* (3), *important* (2) and *desirable* (1). Following this logic, very important criteria contribute more to the organization's preparedness for adopting a PLE approach than desirable criteria. These number values (hereinafter referred to as *suggested importance values*) were defined in four steps: first, all the references in which the criteria or their statements were described in the literature review was counted and listed. Then, the count was segmented into tertiles according to the number of citations found, and a score for each tertile was assigned (Table 4.1). Next, for each criterion, the number of references was counted and checked to ascertain to which tertile the number belonged. Finally, the score associated with the tertile was obtained and this number was assigned as the suggested importance value of the corresponding criterion. The suggested importance value is used during the evaluation to calculate the relative importance of each criterion, as is explained below in step (ii) of the evaluation process in Section 4.2.2.4.

4.2.2 Operationalization

The *Operationalization* level contains the design decisions that were used to make the evaluation tangible. This level, therefore, defines the evaluation methodology, the response formats used to collect data, the performance indicators that summarize the results, the charts used to present the information graphically and the process recommended to conduct the evaluation in a systematic way.

4.2.2.1 Evaluation methodology

APPLIES uses a rapid appraisal methodology to assist newcomers to PLE to evaluate their organization's motivation and preparedness to adopt a PLE approach. This methodology uses both informal and formal modes of data collection and aims to provide decision-related information in a timely and cost-effective manner (Kumar 1993). In particular, data is collected through **self-administered** questionnaires that key informants respond to. This is an adaptation of the key informant interviews method, one of the core methods for rapid appraisal (Kumar 1993).

A disadvantage of self-administered questionnaires is that the data collected may be limited by the respondent's ability to read and understand the statements. Indeed, although there are less subjective methods, such as documentary review or the calculation of quantitative metrics, there is a trade-off between speed and accuracy, since the more accurate the information, the slower and more detailed the data collection must be, and vice versa (Kumar 1993). In most cases decision-makers do not have the option of postponing crucial decisions in anticipation of information. Thus, more reliable information may be pointless if it is not available at the time a decision has to be made (Kumar 1993).

In contrast, self-administered questionnaires favor the rapid collection of data. Furthermore, this type of

rapid appraisal can contribute practically towards analyzing the convenience of adopting a PLE without a need for the extensive commitment of resources required for detailed evaluations. Self-administered questionnaires are, for instance, a less costly data collection strategy than interviews (Switzer et al. 1999).

4.2.2.2 Response format and scoring system

A response format has two purposes: (i) to capture the information elicited and (ii) to transform the captured information into the meaningful units of analysis. These units of analysis are the key blocks for understanding the results of the assessment (Dybå 2001).

The operational level of **APPLIES** includes two response formats for capturing input data that reflect an organization's agreement with the statements provided in the assessment models. Additionally, the response formats provide the basis for transforming inputs into values that represent the organization's performance, in terms of their motivation and preparedness.

- i **Capturing the information elicited [Response formats]**. The operational level defines a binary response format and a Likert-type response format to collect input data. Both response formats are close-ended because they have limited responses, making them fast and easy to fill out for people in organizations. The number of options are balanced as they have the same number of positive and negative options, which serves to reduce response bias. An advantage of both formats is that people are familiar with them because both are used regularly, for example, in surveys. This is explained in more detail below:

Binary response format. The adoption drivers included in the *motivation assessment model* can be selected or not selected. Bearing this in mind, this level uses a binary response format with two binary categories *yes* and *no*.

Likert-type response format. People in organizations may agree or disagree with the statements included in the preparation assessment model. For this reason, this level uses a 6-point scale to collect data regarding an organization's preparedness. This response format has the same number of positive and negative positions and provides the "don't know" and "N/A" options as a neutral value to give respondents a "get out" if they cannot answer the question or are unsure of the response. The description of values for the response format are: (5) totally, (4) almost totally, (3) mostly, (2) somewhat, (1) just a little, and (1) not at all.

- ii **Transforming captured information into meaningful units of analysis [Performance indicators]**. A benefit provided by closed-ended questions is that the responses can be easily aggregated to calculate scores used to synthesize the evaluation results (Carifio & Perla 2007). Performance indicators are quantifiable measurements that help organizations to define and measure progress. The operationalization of the evaluation includes six performance indicators. Two of them are the results from **APPLIES-motivation** and four of them are the results from **APPLIES-preparation**.

- **APPLIES-motivation.** The strategy used to evaluate an organization's motivation is to determine how much agreement there is between historical triggers for adopting product lines that have been reported in industrial experiences and the organization's situation.
 - (i) *Percentage rate of selected adoption drivers.* In the design of **APPLIES-motivation** it was agreed that the more an organization identifies with the adoption drivers, the more sensitive it will be towards adopting a product line engineering approach. This hypothesis is supported by Cohen (2003) who states that the more an organization perceives the need and pressure for change, the more sensitive it will be to adopting a product line approach successfully. In fact,

according to [Susanto \(2008\)](#) most successful change efforts begin when individuals start to look at an organization's situation to identify potential crises or opportunities that may arise. In consideration of this hypothesis, the adoption drivers proposed in the *motivation assessment model* are similar to a checklist and therefore it is possible to count how many adoption drivers were selected.

- (ii) *Share of selected drivers.* The *motivation assessment model* organizes the adoption drivers into four categories: strengths, weaknesses, opportunities or threats. The idea of this indicator is to calculate the share of the selected drivers among the four categories. This information shows whether an organization's motivation for adopting a PLE approach comes from organizational strengths, opportunities, weaknesses or opportunities.

- **APPLIES-preparation**

- (iii) *Score of each assessment criteria.* People score the statements that compose each assessment criteria using the Likert-type response format. Thus, the score of each statement serves to calculate the score for each assessment criterion. This score is the average of the score of each statement. For instance, the criterion *commitment of key actors* has two statements. If the evaluator rates the first statement with “Totally” and the second statement with “Just a little”, the resulting score of *commitment of key actors* is 3.5 which is the average between 5 for “Totally” and 2 for “Just a little.”
- (iv) *SWOT results.* This indicator aims to classify the assessment criteria into opportunities, threats, weaknesses, and strengths according to their score. A value of three (3.0) is the cut-off score that separates positive results from negative results.

The SWOT results depend on the following classification:

- * *Weaknesses and threats.* Internal criteria with a score below the cut-off value are weaknesses and external criteria with a score below the cut-off value are threats.
- * *Strengths and opportunities.* Internal criteria with scores equal or greater than three (3) are strengths, and external criteria with scores equal or greater than three (3) are opportunities.
- (v) *Severity.* To obtain this indicator the assessment criteria are ordered according to their score and relative importance. It is assumed that very important criteria with high scores are more relevant than desirable criteria with high scores. Similarly, very important criteria with low scores are more critical than desirable criteria with low scores. Thus, this indicator provides information for developing action plans to prioritize factors that need attention.
- (vi) *Preparedness score.* This score corresponds to the weighted average between the assessment criteria. The weight of each criterion depends on its relative importance as in the assessment of preparedness, some factors are more important than others. Organizations with a preparedness score below three are considered less or un-prepared. Organizations with a score between 3 and up to 4 are considered partially prepared, and organizations with a score equal or greater than 4 are considered well-prepared, as follows:
 - * Less prepared. The organization is probably not prepared to adopt a product line approach, and the change effort is likely to fail. Organizations should examine the lowest scoring assessment criteria to identify specific areas where they are least ready for the change.

- * Partially prepared. The organization is moderately prepared to adopt a software product line approach. The change effort is likely to be successful only with careful implementation and attention to the issues identified in the lower-scoring assessment criteria.
- * Well-prepared. The organization is highly prepared to adopt a software product line approach. The change effort is likely to be successful as long as organizational leaders and employees remain aligned and receptive to the idea of adopting a product line approach.

The cut-off values are arbitrary considering that good performance is equal or superior to 80%, and low performance is less than 60%. It is expected that these values will be refined as organizations use **APPLIES**.

4.2.2.3 Outputs

APPLIES uses three charts to graphically summarize the performance indicators, as most decision-makers prefer figures over descriptive statements (Kumar 1993).

- **APPLIES-motivation**

- *Alignment with adoption drivers.* A 100% stacked bar chart presents the *percentage rate of selected adoption drivers* in relation to the adoption drivers included in **APPLIES**. A 100% stacked bar chart shows the relative percentage of multiple data series in stacked bars, where the total (cumulative) of each stacked bar always equals 100%, as each series is part of a whole (Evergreen 2017). For this case there are two data series, one that corresponds to the adoption drivers that were selected from the complete list, and the other that corresponds to the remaining ones. Figure 4.5b shows an example of this chart with dummy data.
- *Share of selected drivers.* A pie chart shows the share of the selected drivers across the SWOT analysis. Pie charts are useful to graphically show the proportionate components of a group (Evergreen 2017). In this case, the group corresponds to the selected adoption drivers and the idea is to visualize the distribution of the selected drivers across the four dimensions of analysis. Figure 4.5c shows an example of this chart with dummy data.

- **APPLIES-preparation**

- *Preparation grid.* A colored matrix, similar to a heat map illustrates three related performance indicators in a unified view: *average of each assessment criteria, severity and SWOT results*. There is no pre-designed chart that covers these characteristics. The matrix uses colors as heat maps but also uses the spacial distribution of elements to place the assessment criteria into a SWOT perspective. Strengths and weaknesses are located on the right side of the matrix while opportunities and threats are located on the left side. Similarly, internal criteria are placed in the left chart while external criteria are placed to the right side of the matrix.

The x-axis represents a score from zero to five, and the x-axis has three values corresponding to the relative importance of each criterion. Finally, the color-coded background in the form of a traffic light with variation in hue acts as a visual indicator of performance. In particular the background uses a color progression that goes from red to black. This background aims to call attention to crucial points: the background is red near scores below two for very important criteria, while the background is black near scores above or equal to four for very important criteria. The other parts are colored yellow.

The criteria are then placed in the matrix according to their severity. The average modifies the

position of the assessment criteria in the y-axis while the importance modifies the position of the assessment criteria in the x-axis. Figure 4.7 shows an example of this preparation grid with dummy data.

4.2.2.4 Evaluation process

The implementation of the evaluation consists of three phases: (i) preparation, (ii) execution and (iii) analysis. These phases are similar to those proposed by Schmid & John (2002) in their evaluation framework.

- **Preparation phase.** During this phase, people involved in the evaluation become familiar with **APPLIES**. This means they are able to identify the main components of the framework, the content to evaluate, the response formats, the performance indicators and the charts. **APPLIES** includes an Excel tool to support the evaluation. An additional step in this phase is to download the supporting tool.
- **Execution.** During this phase, data collection and analysis of the results take place. The activities of this stage for each evaluation component are as follows:
 - **APPLIES-motivation.** This follows a three-step process to identify drivers that motivate an organization to adopt a product line approach. These steps are:
 - (i) *Go through each adoption driver one by one.* Users of **APPLIES-motivation** select the adoption drivers relevant to their case from the adoption drivers included in the *motivation assessment model*, using the scoring system defined in this part of the framework. Figure 4.5a shows an extract of the motivation instrument in which users of **APPLIES-motivation** complete their selection.
 - (ii) *Calculate the performance indicators.* The indicators in this step are the percentage rate of selected adoption drivers and the share of selected drivers.
 - (iii) *Draw the results into charts.* Draw the 100% stack bar and the pie chart to summarize the results.
 - **APPLIES-preparation.** This includes a five-step process to evaluate the preparedness of an organization. The steps are:
 - (i) *Customize the importance value of the assessment criteria (optional).* In this step people in charge of the evaluation may define an importance value for the criteria they wish. This information is elicited from users as a number between zero and three. Zero means the criterion is irrelevant to the organization, one means the criterion is desirable, two means the criterion is important and three means it is very important. From here on, this number is called the *customized importance value*.
 - (ii) *Calculate the relative importance for each assessment criterion.* The relative importance of each assessment criterion is the average between the *customized importance value* (explained above) and the *suggested importance*.

In this step information from two different strategies is combined: stakeholder opinions and evidence from the literature. This information is combined as the average of the suggested importance value and the customized importance value. For example, the suggested importance for the criterion *commitment of key actors* is considered very important, which gives it a numeric value of 3. If a user assigns a value of 1, which means desirable, to this criterion, the resulting relative importance will be an average of 3 and 1, i.e. 2, which means “important”. On the

contrary, if the user does not assign any value to the customized importance value of the criterion *commitment of key actors*, then the resulting relative importance will remain as *very important*.

- (iii) *Go through each assessment criterion and rate their statements one by one.* In this step, users rate one by one the statements of each assessment criterion included in the preparation assessment model, using the scoring system. The assessment criteria whose relative importance are equal to “Not applicable” may be omitted because this relative importance means that these criteria are not important for the evaluation.
- (iv) *Calculate the score of each assessment criterion.* This score is the average of the score of each statement. For example, the criterion *commitment of key actors* has two statements. If an evaluator rates the first statement with *strongly agree* and the second statement with *disagree*, the resulting score would be 3.5, which is the average between 5 for *strongly agree* and 2 for *disagree*.
- (v) *Position the evaluation criteria in the preparation grid.* In this step, users position the evaluation criteria in the preparation grid. Each assessment criterion has a position in this matrix depending on its resulting score, its relative importance and its type (internal, external). Internal criteria are placed at the right side of the chart, while external criteria are placed on the left side. Regarding the position with respect to the y-axis, the values change from zero to five. Finally, the X-axis has three values that correspond to the relative importance of each criterion. Figure 4.7 shows a screenshot of this preparation grid with dummy data.

- **Analysis.** In this phase, users of **APPLIES** self-analyze performance indicators and charts to evaluate their organization’s motivation and preparedness for adopting a PLE approach. This information provides data that could help organizations move from the *initiation* stage to the *adoption decision*. This decision could be, for example, to reject the adoption, to continue with the *implementation* stage, or to gather more information before ending the *initiation* stage.

4.2.3 Implementation

The *implementation* level contains the tool that **APPLIES** provides to make the evaluation tangible. This tool is the **self-evaluation instrument** that articulates the two levels and the two components presented above and enables organizations to evaluate for themselves their motivation and preparedness for adopting a PLE approach⁵. This self-evaluation instrument takes the form of an Excel book that offers an out-of-the-box solution for potential users. The tool receives the inputs, automatically calculates the performance indicators and draws the results into the charts for each component. Figures 4.5 and 4.6 show screenshots for both components.

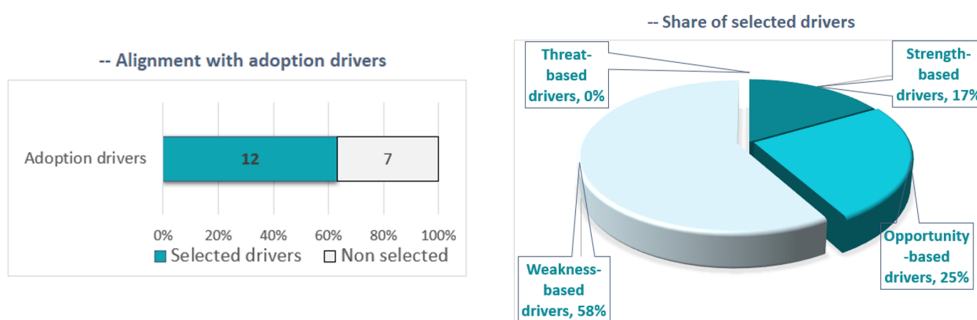
Access to the tool is also simple. Users should go to the project website www.applies.variamos.com, download the latest available version of the evaluation tool, open the file and enable macros to use the Excel tool that **APPLIES** offers. Once opened, users will find three tabs in the Excel book: “APPLIES-motivation”, “APPLIES-preparation”, and “Preparation charts”. The first tab implements the **APPLIES-motivation** component (statements, scoring format, performance indicators draw in charts). The second tab contains the assessment criteria of **APPLIES-preparation** and the third tab contains the preparation grid and preparation score that summarizes the results for the **APPLIES-preparation** component.

A benefit of the Excel version is that people are familiar with this program and therefore the training on how

⁵Evaluation instrument refers to the specific means of collecting the desired information. Definition from <https://www.dictionary.university>

Name	Strength-based drivers	Select all that apply ↓
Retain customers	The organization retains its current customers due to the variability among their products	<input type="checkbox"/>
Gain customers	The organization gains new customers due to the variability among their products	<input checked="" type="checkbox"/>
Legacy code	The company has legacy reusable code that it would like to refactor into a more maintainable form	<input type="checkbox"/>

(a) Data collection form of the **APPLIES-motivation** component. Binary response format



(b) Chart that summarizes the alignment of the organization with the proposed adoption drivers. This sample chart shows that seven over 20 of the adoption drivers were selected in a dummy example case
 (c) Chart that summarizes the share among the selected driver. This sample chart represents that the 58% of the drivers selected were motivated by organizational weaknesses

Figure 4.5: Screenshot showing the results of the assessment tool for **APPLIES-motivation**

to use **APPLIES** can be brief. In fact, the online version only includes a text with simple directions. In addition, people only have to enable macros to use the tool so there is no need to install or configure additional resources on computers.

4.2.4 Requirements - revisited

This section summarizes how **APPLIES** satisfies the functional and non-functional requirements described in Section 4.1.2.

- **[FR1-Motivation]. Assist people in organizations to identify what motivates them to consider adopting a product line engineering approach.** **APPLIES-motivation** provides support to identify the degree of coincidence between the organization’s situation and the drivers of product line adoption identified in industrial experiences.
- **[FR2-Preparation] Provide an overview of factors that influence positively or negatively organizations’ preparedness for adopting PLE.** **APPLIES-preparation** provides support to evaluate different assessment criteria where each criterion could be a strength, weakness, opportunity or threat for adopting a PLE approach. Additionally, **APPLIES-preparation** calculates a score that indicates to what extent an organization is prepared to adopt a PLE approach.
- **[NFR1-Quick evaluation] The evaluation using APPLIES should be easy to complete and should provide results as quickly as possible.** **APPLIES** collects data through self-administered questionnaires, a strategy that aims to collect data quickly and easily, and with minimal investment. The

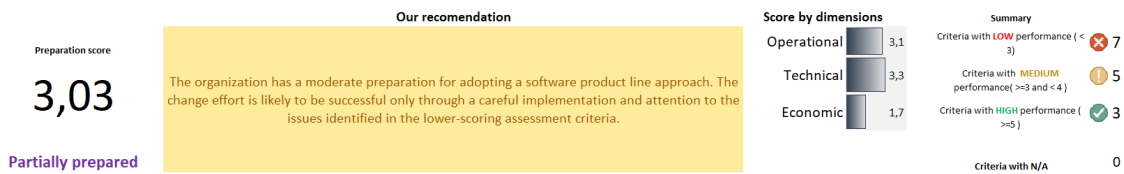
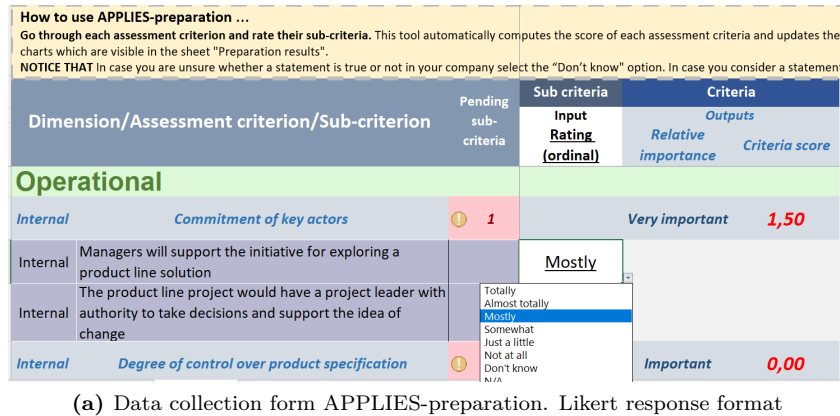


Figure 4.6: Screenshot of the assessment tool for APPLIES-preparation

evaluation is supported by a tool that automatically processes the information and presents results directly after the input is provided. Additionally, since the evaluation of each component is independent and partial results are available, the tool provides flexibility so that organizations can evaluate only specific aspects if they so desire.

- [NFR2-Systematic] **APPLIES** should contribute towards mitigating subjectivity in the decision-making process by providing guides and tools that assist people to conduct the evaluation. **APPLIES** provides a format for systematic evaluation, using a defined set of evaluation factors, a defined data collection methodology, indicators to analyze the results and a way to represent them graphically. Results are calculated in a repeatable manner, by using known formulas and a closed-ended question response format that limits the possibilities of response. The content considered in the evaluation is the product of a literature review that includes multiple sources of information. Because the evaluation factors have been previously defined, the evaluation does not depend on the expertise of an evaluator, but can be conducted even by non-experts in product line engineering. Furthermore, the evaluation process is repeatable and it is possible to identify the reasons that justify the results by reviewing, for example, the score obtained from the statements that make up a criterion.

4.3 Scope and limitations

APPLIES provides not only a conceptual framework that indicates which factors should be assessed in the evaluation, but also proposes an operationalization of the evaluation (how to collect information, document evidence and present results), as well as a tool that implements the proposed operationalization. In this way **APPLIES** offers a solution that covers both the *what* (what factors to evaluate) and the *how* (how to carry out the evaluation). This framework could serve as a consistent point of reference for the PLE community which could, in turn, increase accountability and reduce bias in the evaluation practice.

However, **APPLIES**' scope is limited as it focuses on evaluating the convenience of adopting a PLE approach,

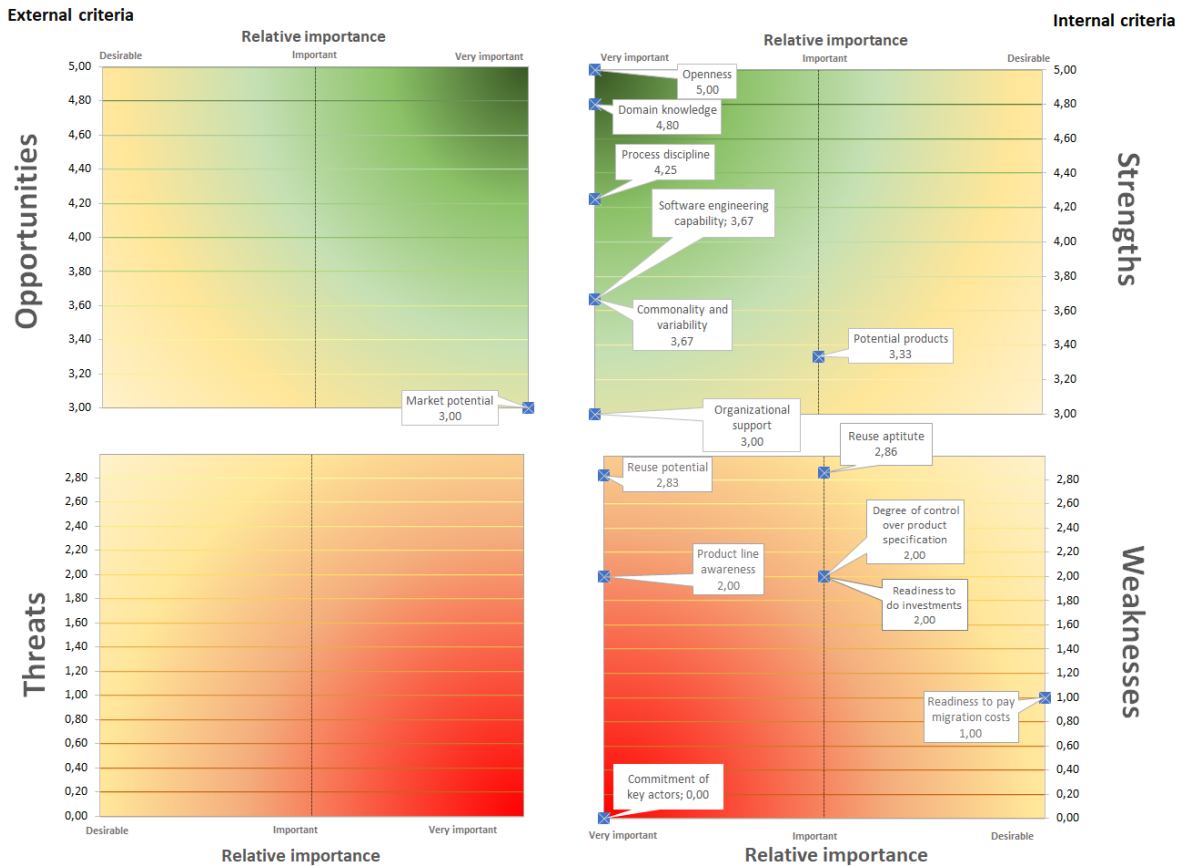


Figure 4.7: Example of the preparation grid chart with dummy data

not on subsequent activities such as adoption planning, implementation or evaluation. The scope of **APPLIES** also excludes recommending alternatives other than adopting a PLE approach. Instead, **APPLIES** provides information to evaluate and prioritize factors that motivate the organization to adopt a PLE. In addition, **APPLIES** evaluates success factors that denote preparedness for adopting a product line engineering approach and identifies those factors that require more attention.

APPLIES does not provide a direct answer to the question: *should an organization adopt a product line engineering approach?* Providing this answer is beyond the scope of **APPLIES**, as there are factors that need to be analyzed by people, such as conflicting needs between stakeholders and the changing and dynamic conditions to which an organization is exposed. Consequently, **APPLIES** does not aim to replace decision-makers. Instead, it provides a systematic means of supporting their judgments prior to making a decision either for or against the adoption of a product line engineering approach.

Finally, **APPLIES** relies on the opinion of an organization’s experts who are selected by the same organization. As a result, it is possible that the sample is not representative of the whole population. For example, junior developers could be underrepresented because they do not contribute directly to an organization’s decision-making.

4.4 Intermediate versions of **APPLIES**

Three versions of **APPLIES** were created during this research. The main structure of the framework remains the same and all versions of **APPLIES** satisfy the same requirements. The changes between the versions were mainly improvements to make the content of **APPLIES** more understandable and to add functionalities in the

supporting tool. This chapter presents the latest version available to the public.

The first version of **APPLIES** (**APPLIES v1**) was produced during the *construction* phase introduced in Chapter 3 Section 3.2.1. **APPLIES 2.0.a.1** and **APPLIES v2.0.a2** are intermediate versions created during the transition between the evolutionary and the complementary multi-method strategies. Table 4.2 tracks these intermediate versions, the differences between each version and the previous version, the reasons for the adjustments, and the empirical evaluations in which each version was used. Changes were cumulative, i.e. the adjustments of **APPLIES 2.0.a1** were maintained for version **APPLIES 2.0.a2**.

Table 4.2: Change log history for **APPLIES** versions

Main version	Version details	Changes	Reasons	Used in
APPLIES v1	1.0.b2	First public version	—	Eval #1 and #5
APPLIES v2	2.0.a1	Improvements in content: wording improvement, merge of redundant statements. Calculation of the overall score regarding organization's preparation for adopting product lines and the score for each dimension. This score is calculated as a weighted average between the assessment criteria (see Figure 4 part b). The weight of each criterion depends on its relative importance. Based on the results, organization with a preparation score lower than three are considered "low prepared." Organization with a score between 3 and 4 (not included) are considered partially prepared, and organization with a preparation score equal or greater than 4 are considered well prepared (see Figure 4 part c) ⁶ .	Integrate evidence collected through the evolutionary multi-method approach	Eval #2 and #3
	V 2.0.a2	Different response format for APPLIES-preparation. This version uses different labels for the response format compared to version 2.0.a.1. Previous versions used labels that go from strongly agree to strongly disagree. Labels in this version go from <i>Totally</i> to <i>Not at all</i> with six possible values in total. The N/A and don't know options were also incorporated to the pool of options. User instructions. Instructions on how to use APPLIES without the researcher's guide were added to the Excel tool.	Test a new response format Incorporate instructions that explain how to use the tool	Eval #4, available to users for download from the website ⁷

4.5 Summary of Chapter 4: The **APPLIES** framework

This chapter presents the development of **APPLIES**, a framework to assist newcomers to PLE to easily evaluate the extent to which a product line engineering approach is, or is not, convenient for an organization, through the evaluation of two constructs: *motivation* and *preparedness*.

Two functional requirements guide the development of **APPLIES**: to assist people in organizations to identify

⁶These values were arbitrarily defined considering that good performance is equal or superior to 80%, and low performance is less than 60% over 100%. It is expected that these values will be refined as **APPLIES** is used in real environments where we can evaluate the influence of the framework on decision making and adjust the values accordingly.

⁷www.applies.variamos.com

what motivates them to consider adopting a product line engineering approach; and to provide an overview of factors that positively or negatively indicate an organization's preparedness for adopting PLE. Additionally, the evaluation tool provided by **APPLIES** should be easy to complete, should provide results as quickly as possible and should contribute towards mitigating subjectivity in the decision-making process, by providing guides and explanations that assist people to conduct the evaluation.

The **APPLIES** framework is composed of three levels: *Conceptualization*, *Operationalization* and *Implementation*. **APPLIES** thus provides a conceptual framework that indicates which factors should be assessed in the evaluation, an operationalization of the evaluation (how to collect information, document evidence and present results), and a tool that implements the proposed operationalization.

The *Conceptualization* level answers the question *what should be evaluated?* in terms of an organization's motivation and preparedness for adopting a PLE approach. Two assessment models drawn from the thematic analysis of related literature provide this conceptual basis: the *motivation assessment model* which includes 20 concrete signals (referred to as adoption drivers) that indicate that a PLE approach could be useful for an organization; and the *preparation assessment model* which organizes evaluation factors into a hierarchy of dimensions, assessment criteria and statements.

The *Operationalization* level contains the design decisions that were used to make the evaluation tangible. Data is collected through self-administered questionnaires that key informants respond to. Information regarding motivation is elicited using a binary response format, and information regarding preparedness is elicited with a Likert-type response format. The responses are aggregated to calculate scores used to synthesize the evaluation results, such as the percentage rate of selected *adoption drivers*, share of selected drivers, scores for each assessment criteria and preparedness score.

Finally, the *Implementation* level provides a self-evaluation tool in the form of an Excel book that offers an out-of-the-box solution for potential users. This tool is useful for capturing user responses, automatically processing them, and drawing results.

The chapter ends by outlining the scope of **APPLIES**' which offers a solution for organizations to evaluate the convenience of adopting a PLE approach: it includes what to evaluate, how to evaluate, and provides a tool to enable users to do this. This section points out that the **APPLIES** framework could serve as a point of reference for the PLE community, increasing accountability and reducing bias in the evaluation practice. Limitations in the scope of **APPLIES** are also acknowledged, for example, that **APPLIES** is limited to evaluating the convenience of adopting a PLE approach, rather than subsequent activities such as adoption planning, implementation or evaluation. It also excludes recommending alternatives other than a PLE approach. In addition, **APPLIES** relies on the opinion of an organization's experts who are selected to participate by the same organization. As a result, it is possible that the sample is not representative of the whole organization's population.

The following chapter presents the results obtained in the evaluation of **APPLIES** regarding its ease of use, content pertinence, perceived usefulness and intention to use.

CHAPTER 5

Evaluation results

The previous chapter presented **APPLIES**, the evaluation framework developed in this research to assist newcomers in evaluating an organization's motivation and preparation for adopting a PLE approach. The synthesis and comparison of the whole set of evidence took place when all empirical evaluations had been completed and each evaluation had been independently analyzed. The results of the entire set of evaluations provide evidence that will help to decide what changes to incorporate in future versions of **APPLIES**.

This chapter presents the results of the evaluation of **APPLIES** by responding to four of the evaluation questions (EQ1 to EQ4) introduced in Chapter 3. Each EQ section, therefore, presents the findings that resulted from the analysis of the evidence collected during the empirical experiences. The descriptions of each finding include quotes from transcripts and Appendix B contains tables with the full set of quotes.

5.1 EQ1 - To what extent do users perceive **APPLIES** as easy to use and why?

This section analyzes the ease of use of **APPLIES** with respect to the response format for capturing inputs (Section 5.1.1), the charts for displaying results (Section 5.1.2) and the tool provided to interact with **APPLIES** (Section 5.1.3). Finally, this section summarizes the main findings regarding the ease of use of **APPLIES** (Section 5.1.4).

5.1.1 Response format

According to the observations made by the researcher in Evaluations #1, #2, and #3, all participants were familiar with the binary response format and the Likert-type response format. None of the participant asked any questions about how to use the response formats and all used both response formats correctly. In addition, although the completion time of each instrument was not measured exactly, in all three evaluations, participants completed the evaluation in less than an hour. These results are positive, as they are evidence that newcomers were able to provide information in a relatively short time using the proposed response formats. Additionally, the design decision of using a closed response format for capturing the input data required by **APPLIES** proved helpful, as it enabled automatic calculation of the performance indicators, allowing participants to interpret the result autonomously.

Other findings related to the response formats include adjustments that could improve their ease of use as follows:

- **A binary response format might not be the best option for capturing data regarding an organization's motivation.** Three of the four participants from Evaluation #2 (which took place

with the software organization) expressed dissatisfaction with the binary response format that **APPLIES-motivation** uses to capture the information. According to the collected comments, a binary format limits a user's freedom as they feel they are making a radical choice when answering the questions. For example, one of the participants said: *“What happens here is that either you say yes, or you say no and that's not necessarily the case,”* (Evaluation #2 - Leader of Innovation).

Also the participants complained that they felt forced to answer “yes” for many of the questions in **APPLIES-motivation**: *“the binary format may lead the respondent to think that he must select “yes” on everything,”* (Evaluation #2 - CEO). This behavior was observed especially when participants responded to adoption drivers relating to an organization's strengths and opportunities. As an alternative, the same participant from Evaluation #2 suggested unifying the response format included in both components of **APPLIES**, saying: *“It seems to me that there is a high contrast between the two evaluation methodologies... I think it is better to have only one,”* (Evaluation #2 - Leader of Knowledge Management)).

On the contrary, the **Likert-type response format (with five values)** performed well in **APPLIES preparation**. It was identified that users liked the qualitative response format for providing inputs in **APPLIES-preparation**: *“I like the nominal scale because sometimes the numbers can be suggestive, so the scale as it is makes one think not about what number to put but about how much one agrees with the statements... I found the scale easy to fill in and I like it that way and not with numbers...,”* (Evaluation #1 - CEO). Similarly, a participant in Evaluation #2 stated: *“I think five answer choices are good. Although the difference between strongly agree and agree is narrow with this scale the position is clear when you agree and when you disagree,”* (Evaluation #2 - Leader of Innovation).

An academic expert also said: *“It seems to me that the evaluation in **APPLIES** is more qualitative than quantitative, so I think the scale is fine. I don't think it is necessary to go into the detail of putting metrics to each statement. Instead, leaving the statements a little more open allows people to discuss them among themselves before selecting an answer,”* (Evaluation #5 - Expert #1).

- **APPLIES** should take into consideration that the adoption drivers might have different levels of importance for different organizations. It was found that the adoption drivers could impact organizations differently depending on their priorities. For example, **APPLIES-motivation** has the following adoption driver: *Product variants are implemented in source code files that are scattered in different parts of the code repository.* If people select “yes”, in the context of **APPLIES** this means that there is a motive for adopting product line engineering. However, during Evaluation #2 one of the participants said: *“Nothing is really controlled here, each project goes its own way, so literally the response to the question is “yes”. However, I answered “no” because in our case, everything works separately and this is not a problem for us, each client has a different product with its own source and this is not a problem, this is how the business works,”* (Evaluation #2 - CEO). Another participant during the same evaluation said: *“you would need a rating more related to how important the adoption drivers are to the organization,”* (Evaluation #2 - Leader of Architecture). Additionally, a participant from Evaluation #3 expressed something similar: *“not all the criteria have the same weight for the organizations. There could be, for example, weaknesses that have a high impact and strengths that even if selected do not bring much benefit to the organization,”* (Evaluation #3 - Group Discussion).

Similarly, when **APPLIES** was used to evaluate the retrospective case of “Acople Tecnológico” (Evaluation #1), the CEO found some statements in the assessment models that were not relevant to his organization: *“With respect to the adoption driver ‘Current products are similar, but were implemented in completely different ways or without interaction between the teams’, my team consisted of only one person, so this*

adoption driver would not apply to me,” (Evaluation #1 - CEO). The CEO from Evaluation #1 was of the same opinion for other factors included in the motivation assessment model. Furthermore, he suggested including an additional option in the response format to offer more flexibility to users where there are statements that do not affect the organization under evaluation, “It is necessary to include in the response format an option that includes an option ‘Does not apply’ with a value of zero or a percentage of zero,” (Evaluation #1 - CEO).

Expert #7 indicated that the motivation to adopt a PLE approach varies by organization. The drivers that may be a strong motivation for one organization may be less strong for another. Also, during Evaluation # 8, Expert #9 recommended including two questions for each factor that evaluates why an organization could be interested in adopting a PLE approach: one about importance and the other about urgency. “You can almost ask two questions: “how important is it, and how urgent is it? If I don’t do it what will happen, what terrible thing will happen? ... those questions might help managers because they have so many things to worry about, that they might be over optimistic. So, if somebody really points out that there’s a problem, it’s important, and it’s urgent and we’re not doing anything about it, there’s motivation,” (Evaluation #8 - Expert #9).

- **The lack of an intermediate value between “agree” and “disagree” in the Likert-scale was noted in the early version of APPLIES.** Regarding the use of the response format, during Evaluation #2, the need to include an additional option into the Likert-scale that represents an intermediate value between ‘agree’ and ‘disagree’ was detected. In particular, three statements were made by participants of this evaluation who felt the need for an intermediate value that did not exist.

As explained in Chapter 4, the format for capturing responses remained the same across all versions of APPLIES for the component on motivation, but was modified for the component on preparation. The new response format was incorporated into the version of APPLIES used in Evaluation #4. This response format was still qualitative and included the following features. First, it incorporated an N/A (Not Applicable) option to increase the flexibility of the response options. Second, it kept the option “don’t know” as a neutral value to give respondents a ‘get out’ if they could not answer a question or if they were unsure. Finally, the linguistic expressions for the response format were modified. Besides “N/A” and “don’t know”, the new labels were: *totally, almost totally, mostly, somewhat, just a little, and not at all*. These labels are consistent with the wording of the statements and included intermediate values between positive and negative labels. This new response format, together with APPLIES in general, was evaluated in Evaluation #4 with an optional satisfaction questionnaire responded to by nine participants. Seven of the nine participants (78 percent) assigned a five to the question related to the format that APPLIES-preparation uses to capture user’s responses (see Figure 5.1). This result is positive because while in previous evaluations some issues were found, as presented above, in Evaluation #4 no negative comments were received in this regard. This result is however preliminary and should be confirmed with more evaluations.

- **A lack of guidance could introduce subjectivity when people select the responses.** The CEO who participated in Evaluation #1 indicated that there were some questions in the instrument where, if he went back to them, he could select a different answer. To address this limitation he suggested including in APPLIES some guidance to help those using the instrument which would lead them to select appropriate values in the response format,

“There are questions that if I revisit them again I might have doubts about what I answered, or that I might answer differently in a future opportunity...this could be resolved if a frame of reference is provided, because

with a frame of reference we would have the guide to arrive at the same conclusions. For example, in our case, version management was not done in Git but in folders. It would be good to know in that case whether it would be better to select ‘agree’ or ‘totally agree’ in the response options,” (Evaluation #1).

Similarly, in Evaluation #4 two different participants used **APPLIES** independently in the same organization and contrary to expectations, one participant recommended adopting PLE while the other did not. Differences were found in most of the responses for both the motivation and preparedness sections. For example, the evaluation criterion “commitment of key actors” had a score of four in one case and a score of two in the other case.

According to one of the industry experts, in his organization they used to think that people could self-evaluate the convenience of adopting PLE once they had taught them how to do it. However, they found people needed more expert guidance: “If you let organizations go off on their own and self-assess, most of the time they never come back because they don’t understand it... people are confused ... we guide them with face to face guidance and we run workshops ...If we’re there and they start to misunderstand something, we can take them and bring them back to the middle of the road,”(Evaluation #8 - Expert # 8). Another expert said: “Your goal of course is to make the self-assessment as accurate as possible,”(Evaluation #8 - Expert # 9).

One participant from Evaluation #2 suggested offering clarification for when to use each possible response option: “The results would be much more accurate if it is clearer what the extreme values of the scale mean and what the intermediate values of agree and disagree mean,” (Evaluation #2). For example, during Evaluation #2 it was observed that participants used “strongly agree” when in their opinion the organization fully complied with the statement of the question, while they selected “agree” when they felt that the organization complied with what was stated in the question but could still improve.

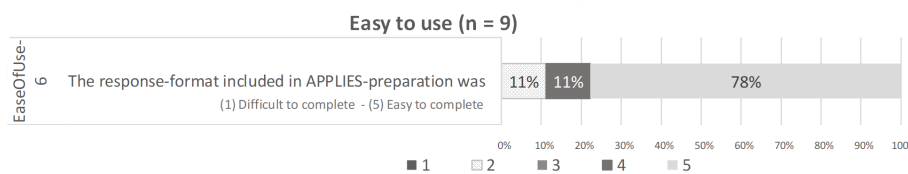


Figure 5.1: Response format

5.1.2 Charts

In general terms it was found that people who participated in the evaluation considered that **the charts were a useful way of presenting results**. Some of the comments that summarize and explain this positive result were:

“I like your pie chart and things like that, it’s a richer way to show data than just an integer,”(Evaluation #8 - Expert #8);

“**APPLIES** offers good outputs because they are a map of the state of the organization. The charts that **APPLIES** delivers are useful for consultants who can go into organizations and analyze whether or not it is worth adopting PLE because you can discuss with them their strengths and problems,”(Evaluation #5 - Expert #1);

“the outputs of **APPLIES** help me to identify criteria that organization members would be willing to change, and to detect those things where there might be some resistance,”(Evaluation #1 - CEO);

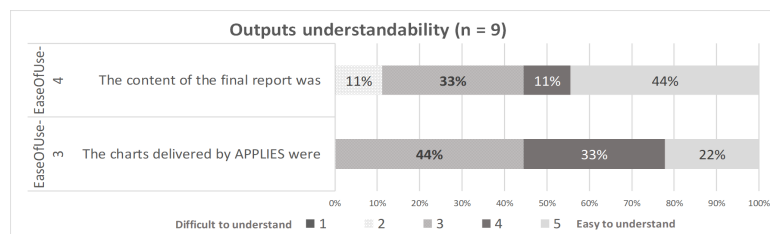
“the way **APPLIES** presents the results can easily be translated into business terms,” (Evaluation #3 - Open Questions);

“I would use **APPLIES** for the summary report that it provides,” (Evaluation #3 - Open Questions);

“These analysis charts are very nice,” (Evaluation #5 - Expert #3).

In spite of the overall favorable opinion regarding the charts included in **APPLIES**, it was found that there is still room for improvement in terms of their understandability and usefulness. Fifty-five (55) percent of the participants in Evaluation #4 (see Figure 5.2) rated the understandability of the charts at four (4) or higher, but the next most common response was three (3) which barely satisfies minimum expected performance. Fortunately, the qualitative evidence indicated aspects that could be improved for each chart, as presented below.

Figure 5.2: Understandability of the Charts. This information comes from nine responses collected in Evaluation #4. Table B.9 in Appendix B presents the frequency, minimum and maximum values found in the responses, as well as the summative results for the items related to this chart



- Alignment with adoption drivers.** This chart summarizes the number of adoption drivers selected during the evaluation in relation to the adoption drivers proposed by **APPLIES**. This chart, therefore, assumes that the number of adoption drivers selected is a good indicator of an organization’s reasons to adopt a PLE approach. However, some comments indicate that there is no appropriate minimum or maximum number of adoption drivers to recommend adopting a PLE approach. For example, one participant from Evaluation #3 stated: “I believe that the number of adoption drivers helps to define a strategy for the implementation of the product line, but not to decide whether to proceed with the adoption or not. For example, if the number of adoption drivers is below two, I don’t think the answer is not to adopt a PLE approach but to implement it in phases,” (Evaluation #3 - Focus Group). Similarly another participant noted that “not all the criteria have the same weight for organizations,” (Evaluation #3 - Focus Group).

Along the same lines, two academic experts commented: “It seems that organizations have to have many of these adoption drivers in order to make it worth adopting a PLE and it doesn’t have to be that way....I believe that making a count of the adoption drivers selected does not really add up,” (Evaluation #5 - Expert #1); “an organization might select more than 60% or 70% and I don’t know if that’s a rate that allows you to make a decision to say yes or no. It is more about the motivation of the person who is using **APPLIES**, but I am not sure that there is a minimum number of adoption drivers that should be selected,” (Evaluation #5 - Expert #5).

The selected comments above indicate that selecting a single adoption driver could be a sufficient condition for adopting a PLE approach. Conversely, even if an organization selects most of the adoption drivers, this should not necessarily be a determining factor for justifying the adoption of a PLE approach, because some adoption drivers might be very important to one organization but irrelevant to another. The conclusion, therefore, is that a chart that summarizes the number of drivers selected in the instrument might not be useful for those who use **APPLIES**. Perhaps because of these limitations to its usefulness 57 percent of

participants (13 of 23) did not use this chart when they analyzed the results presented by **APPLIES** (see Figure 5.3).

- **Share of selected drivers.** The purpose of this chart is to represent the source of an organization's motivation to adopt product line engineering considering four dimensions: strengths, weaknesses, opportunities or threats. However, 35 percent of the participants (8 of 23) did not include this chart in their analysis (see Figure 5.3), which indicates that it was less useful than expected.

Of the remaining 65 percent, 52 percent interpreted the chart correctly, while 13 percent (3 of 23) did not. For these three users, the common problem was the interpretation of the four dimensions. For example, when the chart showed a percentage in the dimension of threats, the interpretation given was that these threats could prevent the adoption. On the contrary, the correct interpretation is that these threats could favor the adoption of a PLE approach.

Included within the group of people who interpreted the chart correctly (12 of 23), one academic expert indicated that the information provided in the chart was useful: *"it can be interesting to know if the organization could adopt PLE because it is a great opportunity for them or because they really can no longer maintain the variants or the development of the products, etc."* (Evaluation #5 - Expert #1). However, other comments show that there were difficulties understanding the chart: *"I find this chart difficult to understand, it could be more suggestive,"* (Evaluation #1 - CEO). Also, the CEO from Evaluation #1 indicated that the percentages inside the chart were difficult to read because the results overlap each other. Additionally, some participants from Evaluation #3 said: *"looking at the chart, I would not know whether or not the organization would be motivated to adopt a PLE approach,"* (Evaluation #3 - Focus Group); *"I think this chart 'share of selected drivers' is not clear,"* (Evaluation #3 - Interview).

Finally, the way in which the chart presents information may bias interpretation since the number of adoption drivers that **APPLIES-motivation** includes in each category (strengths, weaknesses, threats and opportunities) was different. For example, there are 10 adoption drivers in the category of weaknesses and only one adoption driver in the category of threats. This potential for bias was noticed by academic experts who said: *"there are categories of adoption drivers that have more elements than others. This difference can bias the chart; for example, there are more weaknesses than threats,"* (Evaluation #5 - Expert #1); and *"the proportion of adoption drivers is biased by the number of questions in each category. For example, this chart will not show 50% in the category of threats because the total number of threats does not exceed 20% of the total questions,"* (Evaluation #5 - Expert #5).

- **Preparation Grid.** Participants from three different evaluations thought that the information provided in this chart would enable them to know which aspects to analyze before proceeding with the decision to adopt or not. Some comments that highlight this perception are:

"I liked that a summary appears at the end. I want to see in black and white if the product lines would be adequate and the numbers on the chart are clear to me," (Evaluation #2 - CEO);

"This chart gives information on what strengths and weaknesses the organization has to adopt a PLE approach ... This chart gives a very nice overview," (Evaluation #5 - Expert #3).

Overall, there were no comments indicating that the results provided by the *preparation grid* were irrelevant. Another sign of the usefulness of this chart is that, unlike the other charts included in **APPLIES**, the *preparation grid* was used by 82 percent of participants (18 of 22) to analyze the results that **APPLIES** provides (see Figure 5.3). This chart obtained the highest number of correct interpretations and no incorrect interpretations.

However, although most of the participants interpreted the chart correctly, in Evaluations #1 and #5 it was noted that participants needed a few minutes to interpret this chart, while the idea is that people should be able to interpret it in seconds. For example, Expert #1 said, during his think-aloud: “*now that I understand the chart it’s not that bad but it’s complicated to understand,*” (Evaluation #5 - Expert # 1).

Additionally, other contradictory comments were made regarding the understandability of this chart. For example, on the one hand, participants thought that the *preparation grid* was easy to understand and liked the traffic light scheme of colours: “*With the colours black, yellow and red it is easy to detect when something is good, something needs attention and something is bad,*” (Evaluation #1 - CEO); “*The background colors provide information. I understand that what’s black is fine while what’s red is a risk... This chart guides users with the colors and positions,*” (Evaluation #5 - Expert # 3). On the other hand, another participant stated that the chart was difficult to understand: “*I found this chart hard to understand. Only after seeing another colleague’s result I understood that the factors move from the bottom to the top depending on their score. So the same element can move from being a threat to an opportunity and the same goes for weaknesses and strengths,*” (Evaluation #4 - Open Questions).

Other participants indicated aspects that made the chart difficult to understand, such as the distribution of the colours and formatting issues: “*I think it would make more sense to have all the black-colored quadrants on the same side,*” (Evaluation #5 - Expert #1); “*I would have a scale for the four quadrants between zero and five. Then you can have weaknesses that are intensity five and strengths that are intensity five, instead of saying that the weakness is the low number on the same scale,*” (Evaluation #5 Expert # 4); “*The scores are hidden in a text box with size font 8,*” (Evaluation #3 - Open Questions); “*Some numbers in the preparation grid overlap each other,*” (Evaluation #3 - Open Questions).

Finally, the separation in the *preparation grid* between internal and external criteria may be unnecessary considering that the conceptual model that evaluates an organization’s preparedness includes only one external criterion. This suggests that the *preparation grid* should be reviewed to see whether to include more external criteria or whether the separation of the assessment criteria should be removed: “*Either you give up this distinction internal-external, or you need to come up with more external, otherwise it’s useless. Try to come up with more external criteria but if you don’t find any forget this distinction,*” (Evaluation #5 - Expert #4).

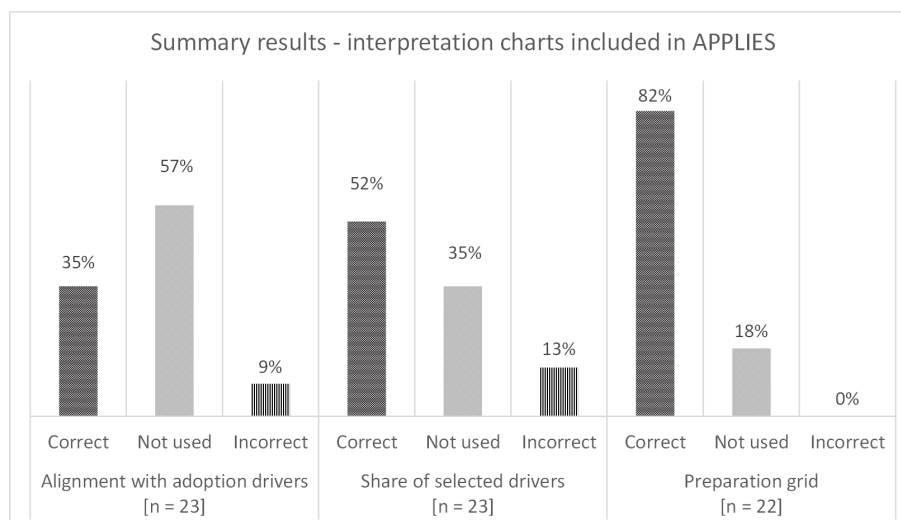


Figure 5.3: Percentage of correct and incorrect interpretations as well as percentage of cases where the charts provided by **APPLIES** were not used. Table B.12 presents the data that support this figure.

5.1.3 Tool support

Overall, it would seem that the Excel tool that operationalizes **APPLIES** is usable. Participants from Evaluations #1, #2, and #3 completed all assigned tasks and had no critical errors using the tool that **APPLIES** provides, under the supervision of the researcher. In Evaluation #4, participants received training on **APPLIES** and then used the tool to evaluate independently (without the researcher), the convenience of adopting product line engineering in at least one software organization. It is assumed that in Evaluation #4 participants did not have any serious problems with the tool that would limit the use of **APPLIES**, as all participants complied with the deliverable, and in the optional satisfaction questionnaire no comments were received indicating problems using the tool. Additionally, as of July 2021 **APPLIES** has been downloaded 209 times¹. So far, no comments have been received indicating that any potential user could not use this tool.

However, some participants expressed their discomfort with the Excel tool that operationalizes **APPLIES**, “I wouldn’t use it for the usability it provides,” (Evaluation #3 - Open Question); “I would change the application. I suffered filling in every question, it’s not clear how it should be used,” (Evaluation #3 - Open Questions); “It is not clear how to use the tool to the point that you need a 10-minute training to use it... it should not require any training,” (Evaluation #3).

In a similar vein, one of the participants expressed that he would prefer a simpler Excel sheet that shows only the columns that are necessary for conducting the evaluation “Although the tool is easy to fill in, I would like to see the Excel workbook cleaner, i.e., showing less information.” (Evaluation #2 - Leader of Architecture). Furthermore, during Evaluation #1 the CEO made some mistakes while he performed the assigned tasks. For instance, he modified or unintentionally erased some text as well as some formulas for calculating the resulting scores. This unintended change happened because the Excel tool did not have protected cells and therefore it was susceptible to accidental modifications.

On a more positive note, eight of the nine participants from Evaluation #4 who responded to the satisfaction questionnaire thought that the instructions for using **APPLIES** included in the tool were clear, as they responded with a score greater than or equal to four ($score \geq 4$) (see Figure 5.4). Furthermore, some participants expressed positive comments regarding the tool, “It’s easy to operate,” (Evaluation #3 - Open questions); “**APPLIES** is easy to use, concise and provides clear results,” (Evaluation #4 - Open questions)

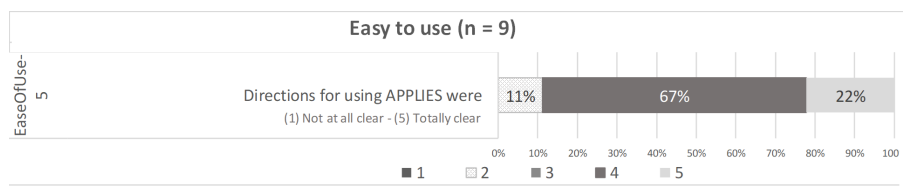


Figure 5.4: Results of the satisfaction questionnaire - understandability of instructions

5.1.4 Ease of use - recap

This section summarizes the findings on the ease of use of **APPLIES** in terms of the choice of the response formats to capture the information, the charts that summarize the results and the tool for entering the data and obtaining the results.

- [Response format] A closed response format is good for capturing input data in the evalua-

¹This number includes downloads of all the different versions of **APPLIES** that have been published

tion. None of the participants asked any questions about how to interact with the proposed response format. The researcher observed that participants understood the mechanics of responding to the statements and could provide information quickly.

- **[Response format] Adjust the options included in the response formats.** According to the findings, the response format to evaluate motivation should include more options for reducing response bias and a mechanism to rate the importance and urgency of factors that motivate an adoption of a PLE approach. Regarding the response format to evaluate an organization's preparedness, additional information should be collected before concluding whether the Likert-type response format is adequate for capturing the inputs needed to evaluate an organization's preparedness to adopt a PLE approach. Response options were adjusted for Evaluation #4, to incorporate improvements that had been made after Evaluations #1 and #2. These adjustments were only tried out in Evaluation #4 with promising results; however, it would be prudent to triangulate the information with results from other evaluations before reaching any conclusions in this regard.
- **[Response format] A lack of guidance could introduce subjectivity when people select the responses.** The response format should provide more information to help users identify the most appropriate response for their case.
- **[Charts] The charts included in APPLIES need improvements to increase their understandability and perceived usefulness.**
 - i The chart *alignment with adoption drivers* is less useful than expected: the problem is not the type of chart itself but the information that this chart presents, as the number of adoption drivers selected is less relevant than expected to explain why an organization would have reasons to adopt a product line engineering approach.
 - ii The chart *share of selected drivers* presents useful information but the way it presents the results might bias the analysis.
 - iii The chart *preparation grid* offers useful information but needs formatting improvements. This chart was considered useful because it presents information that serves to summarize the evaluation results and, in general, the people who were consulted interpreted the information correctly. However, understanding this chart takes longer than desired. One observation made by the researcher is that the *preparation grid* chart gathers 5 dimensions of information at the same time: the list of criteria, the consolidated score of each criterion, the relative importance of each criterion, the type of criterion (between internal and external) and severity. The latter shows the severity of having better or worse values in the criteria score. Thus, although the information presented in the preparation grid is useful to summarize the results of **APPLIES-preparation**, the researcher believes that this chart could be interpreted more easily if the same data were spread across different charts. Moreover, the *preparation grid* received mixed reviews, with some of the participants liking the chart, but others who did not.
- **[Tool] The Excel tool that operationalizes APPLIES was found to be usable but other alternatives to Excel should be explored to improve user-friendliness** The Excel tool was adequate in the sense that people could use the tool to enter the input data and view and interpret the results. Participants involved in the evaluations were able to complete all the assigned tasks and had no critical errors using the tool, and thus the findings show that the usability of the supporting tool allows for successful interaction between users and the evaluation they were able to perform using **APPLIES**. However, the findings do not lead to the conclusion that *Excel is the best way to implement APPLIES*, as some people expressed their

discomfort with the Excel tool and it was susceptible to accidental changes in data. The idea of exploring alternatives to Excel for the tool is a new hypothesis that emerged and should be analyzed further.

5.2 EQ2 - To what extent is the information included in **APPLIES** sufficient to evaluate the convenience of adopting a PLE approach?

This section presents the positive and negative findings related to the content of the *motivation assessment model* (Section 5.2.1) and the *preparation assessment model* (Section 5.2.2). Both models constitute the conceptual basis for carrying out the evaluation with **APPLIES**. Then, Section 5.2.3 compares the content of the *motivation assessment model* and the *preparation assessment model* with evidence collected from academic and industry experts. Section 5.2.4 compares the relative importance assigned to the factors included in the preparation assessment model that belongs to **APPLIES-preparation** to the relative importance elicited in Evaluation #6. Section 5.2.5 presents the results regarding the understandability of the content included in the assessment models. Finally, Section 5.2.6 summarizes the main points that answer this evaluation question.

5.2.1 Motivation assessment model

The *motivation assessment model* uses statements to identify reasons that might motivate an organization to adopt a PLE approach. This model consists of 20 adoption drivers separated into four categories: strengths, weaknesses, opportunities and threats. The findings related to the content of this assessment model are presented below.

- **Review the structure of the adoption drivers to avoid interrelated statements.** An academic expert suggested reviewing in detail the *motivation assessment model* because he considered that this model had overlapping elements:

“I think you need to identify different dimensions. Here they are all mixed up ...it looks like the set is taken from a larger set of possibilities and we don't see a clear structure or systematic analysis in this list. That's why it's important to think of dimensions before thinking of lists of stuff. Ideally when it's well structured and controlled the list emerges from the dimensions, you cross the dimensions and then you know the possibilities,” (Evaluation #5 - Expert #4).

According to this expert, one reason for the overlapping is that different levels of abstraction are mixed in the motivation assessment model. For instance, some weakness-oriented adoption drivers are related to technical artifacts, while others are related to business processes. Problems in technical artifacts can be the result of problems in business processes, which would lead to overlap. Other drivers where overlaps were found were: *Gain customers and New Market; Similar market and New market; Similar market, similar incoming plans and technology advances; Customize products in short time and New market; Scattered source code, uncontrolled product parts, and Similar products implemented differently.* Table B.3 in Appendix B presents the complete set of adoption drivers included in **APPLIES**

- **Review the discriminatory power of the adoption drivers included in the motivation assessment model.** The adoption drivers included in **APPLIES-motivation** should assist organizations to identify when they have reasons to adopt a PLE approach. However, when the instruments collected in Evaluation #4 were analyzed together, it was found that they all had at least five adoption drivers selected. Thus, it was expected that the participants would recommend the adoption of a PLE approach

in all cases. However, there were four cases where, regardless of the adoption drivers selected in **APPLIES**, participants felt that there was no reason to adopt PLE. This finding could indicate that **APPLIES** has adoption drivers that are unhelpful in supporting organizations to identify when they have reasons to adopt a PLE approach.

A similar finding appears when participants from Evaluation #2 suggested that **APPLIES** included factors that many organizations would like to achieve even if they do not need a PLE approach. In particular, one participant from Evaluation #2 said:

“This type of solution rapidly helps organizations to get an idea of whether the product lines could be useful to the organization. However, I am left with the doubt of when does one say no? Because the questions lead you almost always to say yes. ² That is, answering ‘no’ would not be possible ... Our business is a custom software development organization, so everything that has to do with software development fits, and everything that has to do with new technologies in software development also fits our case,” (Evaluation #2 - CEO).

Similarly, one of the academic experts said: *“I don’t even have an organization and when I read the adoption drivers that **APPLIES** currently has I would answer yes because you are asking almost only about the benefits... There are many other ways to solve the problems you are showing in the adoption drivers, and it is not necessarily software product lines that have to be the solution. For example, almost everything proposed in software engineering is focused on correcting the weaknesses described by the adoption drivers. What you have here could be motivating, but in reality there are more ways than product lines to solve them,” (Evaluation #5 - Expert #5).*

- **Suggested new drivers.** Seven topics related to the motivation for adopting a PLE approach were collected from the evaluations. These topics were classified into categories that fit within the current structure of the motivation assessment model.
 - **Threats:** *Speed with which the organization must respond to customer requirements; New technology that makes it possible to extend variability; and Competitors.*
 - **Opportunities:** *Obtain savings by producing similar products; Gain expertise in a market segment; Diversify the market; Need to acquire a market segment; and Need to increase product quality.*

5.2.2 Preparation assessment model

The *preparation assessment model* uses statements to identify an organization’s preparedness to adopt a PLE approach. This model organizes its content around three dimensions, 17 criteria and 67 statements. Table B.4 in Appendix B presents the complete model and the findings related to the content of this assessment model are presented below. In many of the explanations, the statements are mentioned together with a number. This number corresponds to the identifier of the statement in Table B.4.

In general terms, positive comments were received on the content included in the *preparation assessment model*. Table B.18 shows the full set of comments collected on these topics. For example, the CEO from Evaluation #1 stated: *“It seems to me that **APPLIES** addresses the right topics like reuse, variability, commonality, etc.... I think the questions are well focused on operational, economic and technical aspects,” (Evaluation #1 - CEO).*

Similarly, participants from Evaluation #3 and Evaluation #4 commented:

²This idea was supported by the innovation manager and the leader of architecture.

“It seems to me complete regarding the key points of weaknesses, threats, strengths and opportunities that the organization has,” (Evaluation #3 - Open Questions);

“**APPLIES** covers not only the organization’s technical capabilities but also the organizational aspects and interests that the organization might have from a business perspective. This coverage generates strong confidence in the evaluation,” (Evaluation #4 - Open Questions);

“**APPLIES** takes into account the different factors that are affected when implementing a product line,” (Evaluation #3 - Open Questions).

One of the academic experts said: “In **APPLIES-preparation** it seems to me that the criteria are very well developed... I like it,” (Evaluation #5) while another academic expert said: “It seems to me that the statements cover what an organization should evaluate before starting a product line engineering approach. The comments for improvement are small and specific,” (Evaluation #5 - Expert #5).

Regarding aspects to improve in the *preparation assessment model* recommendations were made on statements that could be removed or amended, either because they were irrelevant to the evaluation or because they were difficult to evaluate at an early stage of the decision process. Also, it was noted that there were some statements with risk of bias, some overlapping statements, and a statement that could be split. Each of these cases is explained below:

- **Irrelevant statements.** After the first round of evaluations (Evaluation #1 and Evaluation#5), two statements were eliminated: *the organization is a pioneer in the development of products* (Statement 18) and *the organization has strong software engineering capability* (Statement 58). The first statement was eliminated because it represents a situation that could be ideal for many projects, but is not an exclusive requirement for adopting a product line engineering approach. The second statement was eliminated because it is an abstract concept that is evaluated concretely with other statements that belong to the same assessment criterion.

Other statements that could be removed from the assessment model were identified when the results of the evaluations were analyzed together. These statements can be removed as they are not decisive factors in considering the adoption of a PLE, but instead could be an advantage for any type of project. Below, the statements are presented together with the comments from the evaluations that justify their removal.

- **Customer connection (Statements 3, 4, 5, and 6).** “Organizations want to get new customers and keep the ones they get, but those criteria are more of an organization’s concern than a sign of preparation to adopt product lines,” (Evaluation #5 - Expert # 5)

“It’s a general characteristic of the organization, but whether it has a variability management issue or not.... Coca-Cola is able to attract new customers and it does not have a relation with PLE,” (Evaluation #5 - Expert # 4)

- **Being among the market leaders (Statement 17).** Expert #5 from Evaluation #5 indicated that this is a general criterion that is not directly related to adopting a PLE approach. Also, this expert suggested that organizations that use **APPLIES** are unlikely to be market leaders: “if the organization develops general-purpose software, the most likely is that there are larger organizations in the market, and for customized software, a market share is not defined ,” (Evaluation #5 - Expert #5). Expert #8 also indicated that this statement was not important for PLE adoption.
- **The organization has the potential to offer new products that the market has not anticipated (Statement 9).** “Having the potential of offering products that the market has not anticipated

is a benefit of adopting a PLE approach not a sign of preparedness for doing it,” (Evaluation #4 - Expert #4)

- **Proprietary tools used to develop the current products are not a barrier to adopting a product line approach (Statement 61).** *“I don’t consider that the use of proprietary technologies, such as Visual studio and .Net are an impediment to adopting a PLE approach,” (Evaluation #5 - Expert #2) “Not sure about the consequences of that,” (Evaluation #5 - Expert #1).* This statement was also marked as unclear by some participants in Evaluation #4. Statement 61, therefore, was difficult to evaluate and did not seem to bring any added value to the evaluation of an organization’s preparedness.
- **Statements difficult to evaluate.** The goal of **APPLIES** is that it should be usable by organizations that have not yet decided to proceed with the adoption of PLE. The following statements were therefore deemed impractical as they require deeper analysis and more experience in adopting a PLE approach.
 - **Economic estimations.** Statements 62 and 63 in Appendix B.2 were difficult to evaluate immediately because they ask for concrete data about the business model and the estimated return on the investment (ROI). However, as organizations that use **APPLIES** have no experience with PLE they do not have enough data or expertise to respond to these questions. This finding was identified in Evaluations #2, #3 and #5.
 - **Technology with which the product line will be implemented.** According to Expert #5, the statement relating to the technology that will be used to implement the product line (Statement 60 in Appendix B.2) is difficult to answer because this information may be uncertain at the time organizations are considering adopting a PLE approach. This expert indicated that the question should rather be oriented towards asking about the organization’s willingness to use new technologies, for which **APPLIES** has already included a statement (Statement 29): *“if people do not know details about what the product lines are, they will not know in which technology the product line will be implemented because there can be many things. For example, variability can be implemented in many different ways. The question should rather be oriented to identify if the people in the organization are willing to learn new technologies that allow the implementation of a product line,” (Evaluation #5 - Expert #5 -)*
- **Statements with risk of bias.** An expert from Evaluation #5 indicated that four statements in the *preparation assessment model* are prone to social desirability response bias. The following is one of those statements: *Individuals in the organization are open to change how they interact with colleagues and other departments.* Bias occurs because respondents tend to deny negative answers and respond in a way that is more (socially) desirable in their work context (Given 2008). The expert mentioned only four statements (Statements 23, 24, and 45 in Appendix B.2) but it is possible that that all statements asking for opinions might have this failing. In particular, **APPLIES** includes statements to evaluate an organization’s willingness to change (Statements 23, 24, 26, and 46), to learn (Statement 29), to collaborate (Statement 27), to assign people to the adoption initiative (Statement 39), ability to pay maintenance costs (Statement 36), and ability to pay for the cost of adopting a PLE approach (Statements 38, 65, 66, 67). Thus a total of twelve statements included in the *preparation assessment model* may unintentionally include social desirability response bias.
- **Statements to split.** One participant from Evaluation #2 stated that **APPLIES** had statements that evaluate two different things at the same time. Only one statement in the *preparation assessment model* had this defect and needed adjustment (*the organization staff has knowledge about product line engineering.*

Otherwise, they are willing to learn (Statement 37)). This statement included two aspects in the same question: whether the organization knew about product lines and whether it would be willing to learn about them.

- **Interrelated statements.** After the first round of evaluation seven statements were combined because they overlapped with other statements. For example, the statements: “current customer needs are known”, “future customer needs could be predicted” and “the organization could predict the evolution of the products” were merged into the statements “A future market for the products under the scope of the product line is foreseeable.” Table B.4 presents details regarding the adjustments made after the first round of evaluation.

However, when the results of the evaluations were analyzed together it was found that some users expressed that they felt they were responding to the same questions several times: “I consider that some questions are repetitive, several times I returned to check if I had not already answered them,” (Evaluation #4 - Open Questions). Similarly, two of the academic experts noted that: “The categories are good but many are very interrelated,” (Evaluation #5 - Expert #4); and “It seems that certain criteria are repeated,” (Evaluation #5 - Expert #5). In order to find statements that unintentionally overlapped, the statements included in **APPLIES** were grouped by topic. One observation that emerged from this distribution is that some statements within the same group might be unified because they evaluate similar constructs. As an example, Statements 33, 35, 47, 48, 50, 51, 52, 53, 54 and 56 refer to artifacts that already exist in the organization and Statements 43, 44, 45, 49 and 59, refer to organizational practices that make it easy for the organization to follow a reuse approach. Both groups could be simplified, for example, into a single statement for each case. Avoiding duplication of statements is important to keep the assessment model brief, which is useful for maintaining attention and reducing the effort of those doing the evaluation.

5.2.3 Content coverage

This section compares the statements that make up the *motivation assessment model* and the *preparation assessment model* with evidence collected from experts in Evaluations #5, #6, #7, and #8, in order to evaluate the content coverage of **APPLIES**. The analysis includes first, the coverage on criteria that identify whether a PLE approach meets an organization’s needs, and second, the coverage on criteria that denote an organization’s preparedness.

Coverage on criteria that identify whether a PLE approach meets an organization’s needs

During Evaluation #7, the industry experts considered three elements for identifying whether a PLE could meet an organization’s needs: (i) *there are problems that the organization needs to solve*; (ii) *an organization’s problems might be resolved by implementing product line engineering*; and (iii) *it is important and urgent for the organization to resolve its problems*.

For each element, the coverage of the *motivation assessment model* was analyzed as follows:

- i **There are problems that the organization needs to solve.** Problems rather than opportunities motivate organizations to consider adopting a product line engineering approach: “Nobody does this because it is a good idea, because they want elegance in their solutions. They do it because something is really hurting them,” (Evaluation #7 - Expert #9). Similarly, Expert #10 commented: “In most cases organizations don’t see an opportunity; that’s not the criterion when they decide to work for product lines. They see problems coming or they already have them, or it’s very easy to predict that they’re going to have serious problems more or less soon,” (Evaluation #7 - Expert #10)). Expert #8 complemented this idea by saying: “Usually we look for pain, misery, fear, and if we find that, that’s the perfect environment,” (Evaluation #7 - Expert #8).

Similarly, Expert #10 said: *You're mostly invited at a point where organizations already see a problem ... they know they may have a shortage of personnel, or they are not able to keep up with what they are supposed to do, with their process, etc. So, the main question they ask is: 'how can we solve that problem?'* (Evaluation #7 - Expert #10).

This expert also said: *"You have two cases. One is that someone is seeing a problem and it is not clear what the solution to the problem would be and then hears that PLE could help them and asks you to introduce it. The other case is more successful and occurs in the cases of those organizations that already have something similar to a product line with some missing pieces,"* (Evaluation #7 - expert #10).

The adoption drivers that **APPLIES** includes in the category of weaknesses and threats were aimed at identifying potential problems that could motivate adopting a PLE approach. However, as was explained in Section 5.2.1 the current version of the motivation assessment model needs adjustments so that organizations are able to differentiate between when there are reasons to adopt a PLE approach and when there are not.

ii **An organization's problems might be resolved by implementing product line engineering.**

Three cases identified in Evaluation #7 indicated when a PLE does not meet the needs of organizations: (i) *when the organization needs to produce less than three products*, (ii) *when maintenance or evolution tasks do not represent a problem for the organization*; and (iii) *when the problems of the organizations are related only to variability in time*.

- (i) When the organization needs to produce less than three products. This number is consistent with the value reported in the literature to achieve the benefits promised by a PLE approach, as some initial effort has to be made when adopting PLE, but once the infrastructure is in place, it is expected that the payoff will commence (Knauber et al. 2002). Fritsch & Hahn (2004) also believe that a PL may not make sense when there are not enough products.

The topic was discussed by the experts as follows:

"If you only have one or two, there is not enough benefit... You get some benefit with two, but the benefit is not enough for people to say yeah, let's continue. I think this is a stop signal, if we see that, we say don't do it," (Evaluation #8- Expert #8).

"Theoretically, it is sufficient to have two to three features, or whatever variations you have, to create a product line with three products, but in most cases the most difficult thing is not to design a system which is able to deal with a few variations. We have had organizations that started with just one or two products, but they're looking to the future and they know that every year there will be two more, three more, five more products that they will have to maintain. But in contrast, if you ask how many products will you introduce? and, for example, the answer is five but over a period of five years, then we say 'don't use it' or you could do it but it's not necessary to run a product line approach with that simple number..." (Evaluation #8- Expert #9).

The *preparation assessment model* includes a statement that asks for the number of products that a product line would produce. This statement (Statement 33) is one of the three statements that belong to the criterion *potential products* where relative importance is desirable. It is necessary then to give greater importance to this statement because it is a signal that could inhibit the adoption. Expert #8 indicated that potential products should have a short-term scope: *"you have to define what you need now and look ahead just a little bit ... trying to look ahead into the future to create features and variation points that might be never used is a waste of time."* (Evaluation #8- Expert #8). Krueger (2010) proposes a time horizon of between three and six months.

Finally, and in contrast to the accepted number reported in PLE-related literature such as [Knauber et al. \(2002\)](#), one of the academic experts in Evaluation #5 suggested verifying if three products are enough to consider PLE: “*Three is too little to justify a product line. A three-product line is like killing a fly with an atomic bomb,*” (Evaluation #5 - Expert #4). Similarly, in Evaluation #6 one of the experts suggested that five should be the minimum number of products needed to make an adoption worthwhile. Thus, **APPLIES** could consider three as a minimum number of products, but this value may be adjusted over time as the framework evolves and improves.

- (ii) When maintenance or evolution tasks do not represent a problem for the organization. In some cases, maintenance and evolution management are not a problem but rather part of the business. On this topic, Expert #10 said: “*If you throw away your products, if your maintenance is not a problem for you and you want to quickly do the next product and kind of forget the previous one... In those cases you say to the company: you’re better off with clones,*” (Evaluation #7 - Expert 10). The *motivation assessment model* currently includes three adoption drivers on this topic (Statements 10, 11 and 17), but other adoption drivers that better represent maintenance issues could be added.
- (iii) When the problems of an organization are related only to variability in time. In this case, the organization requires solutions to handle multiple versions of the same product but not multiple products at the same time.

On this topic the expert Expert #8 said:

“We get people who will get pretty far into a conversation and realize they’re just trying to manage a release of a product last month and then they release that same product this month, so they have to maintain that old one and the new one, and then pretty soon they have to maintain ten older versions but it’s just one product, and that’s uninteresting. We don’t treat that as a product line ... Evolution of a product is not a product line. We would say that a product line or a product family means that at this point in time I’m going to release five different ‘flavors’ of my products,” (Evaluation #7 - Expert #8)

The *motivation assessment model* includes two adoption drivers (Statements 15 and 19) that evaluate similar aspects. Additionally, the *preparation assessment model* includes statements that serve to evaluate that the domain of interest complies with the characteristics that a product line solution requires: that there are common and variable elements among the potential products (Statements 40, 41 and 42).

- iii **It is important and urgent for the organization to solve its problem.** **APPLIES** did not consider the issue of urgency, as explained in the findings on the response format (see Section 5.1.1), but according to the experts, both importance and urgency are key issues to consider when trying to convince people to go ahead with the analysis, until eventually implementing the adoption.

“If the benefits that the PLE offers are good enough to convince someone, it depends on how many issues they have with that problem,” (Evaluation #7 - Expert # 10).

“Organizations might have other visions, such as trying to adopt a new kind of technology... then organizations just might say: ‘it’s important but we have other more important things to do right now’,” (Evaluation #7 - Expert # 8).

“We usually separate importance and urgency. You identified the importance. Something can be very important, and a company would say ‘I’m busy this year, I’ll do it next year’, and then you get to the next

year and it says 'it's still important but I'm really busy'. So unless it's urgent, people don't do product lines, even if they see it's really important," (Evaluation #7 - Expert # 8).

In addition, one of the experts explained that the three main ingredients to introduce a change successfully in any organization are urgency, importance and communication: "The way you effectively enable an organization to adopt something new contains easy ingredients: finding urgency, finding importance, measuring your first successes and communicating that to create more successes," (Evaluation #7 - Expert # 8).

Regarding urgency, Expert #10 stated, "If you don't have explicitly measurable pain or a clear statement that is believed by the people in the company who have power, you won't see any movement. They just wait for something to happen," (Evaluation #7 - Expert # 10).

Coverage on criteria that denote an organization's preparedness

During Evaluation #7 four barriers to PLE adoption were identified: (i) lack of support; (ii) lack of maturity in the engineering processes; (iii) lack of budget for investment; and (iv) lack of customer readiness. These barriers represent important aspects to evaluate in order to understand to what extent organizations are prepared to adopt a PLE approach. Below, the coverage of these issues provided in the *preparation assessment model* is analyzed and compared with the results of other evaluations:

- i **Lack of support.** Personnel from the administrative and the technical side should be convinced and involved in the adoption project, as the success of the whole process depends largely on these key people and their willingness to embrace the initiative:

"Overall, if the organization just doesn't want to, if nobody wants to, then they're gonna fail... If there's no willingness, that's a problem," (Evaluation #7- Expert # 8)

"One of the things we observe when you try to get organizations to do PLE is that the success is very much dependent on individual people," (Evaluation #7- Expert # 9)

Also, according to Expert #8 technical leadership is as important as business leadership: "You need both a technical leader to sell to everybody technical, and somebody in charge of engineering but from a management business point of view who sells the business side... So, usually there's a chief engineer or chief architect, somebody that understands the system technically, and then there's a technical leader who can guide the technical organization to adopt a product line engineering approach. So, he's somebody that is respected and trusted and technically if he says: 'we think product lines are good', then he can work down through the technical organization that makes it happen," (Evaluation #8 - Expert #8)

Regarding support for the adoption, the *preparation assessment model* includes statements that evaluate support from top managers (Statement 1), the existence of a project leader (Statement 2), the staff's openness to change (Statements 23, 24), the willingness of staff to collaborate (Statement 27), the willingness of staff to learn (Statement 29) and finally, the organization's openness to change (Statement 26).

- ii **Lack of maturity in engineering processes.** In Evaluation #7, two of the experts indicated that it is very important for the adoption of a PLE approach that the organization has a certain maturity in its processes, especially in terms of configuration management practices and testing.

"It's sort of a thing that we work at to measure - if an organization can do configuration management it's an indicator of how healthy they're and if they cannot do that then they cannot add variation management in addition to configuration management. So if they cannot do that, that's a problem. So I think it's important in general. If they cannot do this thing, they're not skilled and healthy enough for adopting

product lines,” (Evaluation #7 - Expert #8)

“There needs to be a certain maturity of the organization in terms of engineering, and if they’re not happy with this, you can fix a few things while you’re doing the product line thing, but if the all work quality is in bad shape, you should say no, because product line engineering amplifies all of these problems... For example, if you don’t test well a bug can creep up in more than one product at the same time,” (Evaluation #7 - Expert #10)

The *preparation assessment model* of **APPLIES** includes the criterion *process discipline*. However, the statements included in this criterion evaluate different aspects to those mentioned by the experts: they evaluate whether the organization follows any quality practices such as CMMI (Statement 34), whether the organization follows defined processes for documenting requirements (Statement 35), whether the organization has explicit documentation (Statement 36) and whether the organization has practices for maintaining assets (Statement 37).

Taking into account the comments collected from the experts, the *preparation assessment model* should maintain the criterion that evaluates maturity in an organization’s engineering processes although **the statements included in this criterion should be adjusted to take into consideration whether the organization follows a repeatable process**. Also, a statement should be added regarding whether organizations have processes to carry out tests. Additionally, Statement 5 of the *preparation evaluation model* asks about the configuration of management practices, but this statement was part of the *software engineering capability* criterion and should be moved to the *process discipline* criterion.

- iii **Lack of budget for investments.** Experts #8 and #10 indicated that it is very important that organizations have the necessary economic conditions and a willingness to invest financial resources. According to Expert #8, even if the adoption starts with a pilot project, the organization will eventually need to invest resources:

“This is a key piece that we always struggle with. Organizations always struggle with that, and if they can’t find the budget then they have problems. From an incremental point of view, you can run a pilot, but you still have to make a decision to adopt, and if you don’t have budget, it is just going to fail...,” (Evaluation #7 - Expert #8).

The availability of resources to invest is very important for the success of a PLE adoption and **APPLIES** already includes a statement that asked about this availability (Statement 64). In addition, **APPLIES** includes statements that ask about an organization’s willingness to invest resources in the activities needed to create and maintain a product line (Statements 38, 65, 66, and 67). Expert #5 recommended including in the formulation of Statement 67 information about the other costs involved in the adoption, for example, for activities such as performing the commonality/variability analysis, defining what products will constitute the product line, identifying the variability points, designing and developing the reusable artifacts, etc. Furthermore, distributed among other criteria **APPLIES** also includes statements to evaluate an organization’s willingness to assign people to the adoption initiative (Statement 39) and the organization’s willingness to pay the maintenance costs (Statement 36). Also, as suggested by one of the experts, the statements of the *readiness to invest* criterion could be unified with the *readiness to pay migration costs* criterion. **APPLIES** also includes statements asking about economic indicators (Statements 62 and 63). However, the *preparation assessment model* should discard Statements 62 and 63 because, as explained earlier in this section, people do not have enough information to answer them during the initiation stage of the innovation decision process.

iv **Lack of customer readiness.** A PLE adoption should also be considered from the business perspective if those who receive the products, especially whether customers would accept the implications of adopting a PLE approach, such as continuous updates or a shared base of assets. On this topic Expert #10 stated:

“A business motivation not to adopt PLE is that organizations have a lot of customers who they think they will not accept small changes or big changes that come with the product line approach from time to time, for instance when the software is updated ... it is important to put yourself in the customer’s place and consider whether they will accept what comes with a product line,” (Evaluation #7 Expert #10). **APPLIES** does not include any statement on this topic, therefore statements that evaluate customer readiness should be incorporated into the *preparation assessment model*.

5.2.4 Importance of the assessment criteria in the *preparation assessment model*

The relative importance of each assessment criterion in the *preparation assessment model* offers information regarding the most critical points of attention that would indicate an organization’s level of preparedness. This sub-section analyzes the relative importance elicited in Evaluation #6 for criteria that make up the *preparation assessment model*. In this evaluation Expert #6 and Expert #7 independently ranked each assessment criteria in one of the following categories: *very important*, *important*, *desirable* and *irrelevant*. In addition, in some cases the analysis was further enhanced by topic-related comments collected in Evaluations #5 and #8.

Table 5.1 presents the collected data. Rows in the table show the assessment criteria, while the columns correspond to the importance suggested by **APPLIES** and the importance assigned by each expert³.

An observation that results from this evaluation is that experts encountered difficulties in deciding on the difference between the closest categories i.e., between *very important* and *important* and between *desirable* and *irrelevant*. In other words, while the separation between the categories at opposite ends was clear, the difference between closer categories was blurred. For this reason and for easier analysis, the sub-section below groups the results presented in Table 5.1 according to the two extreme categories: *very important/important* and *desirable/irrelevant*. Furthermore, this sub-section presents a new category, *cross-cutting* criteria, which emerged during the evaluation.

- **Very important/important criteria:** there were four criteria that both **APPLIES** and the two experts considered either *very important* or *important* in Evaluation #6: *commitment of key actors*, *organizational willingness*, *openness*, and *commonality and variability*. Both Expert #6 and Expert #7 suggested that the two criteria *commitment of key actors* and *organizational willingness* share common interests and could perhaps be consolidated under one of the headings.

Additionally, both experts felt that two criteria were important to evaluate economic readiness: *readiness to invest* and *readiness to pay migration costs*. However, one of the experts had doubts regarding the word ‘migration’ in the *readiness to pay migration costs* criterion, because if an organization has no assets there would be no migration costs. When it was explained to the expert that this criterion referred to having the resources to pay the costs associated with an adoption, he indicated that it was similar to the criterion *readiness to invest* and therefore the statements of both criteria could be unified.

There were mixed opinions regarding the *domain knowledge* criterion. Expert #6 rated this as low importance and was unsure whether to grade it as *desirable* or *irrelevant*. He believed that while it may

³The *economic indicators* and *customer connection* criteria were not included in this evaluation as they were removed from the *preparation assessment model* in the transition between **APPLIES v1** and **APPLIES v2**.

Table 5.1: Comparison among the relative importance for assessment criteria that constitute the preparation assessment model. Source: author's compilation from responses collected from Expert #6 and Expert #7

Criteria	APPLIES	Expert #6	Expert #7
Commitment of key actors	Very important	Very important	Important
Organizational willingness	Very important	Very important	Important
Openness	Very important	Very important	Important
Commonality and variability	Very important	Very important	Important
Readiness to invest	Important	Very important	Important
Readiness to pay migration costs	Desirable	Very important	Important
Domain knowledge	Very important	Desirable Irrelevant	Very important
Potential products	Desirable	Between very important and important	Important
Software engineering capability	Very important	Cross-cutting criterion	Cross-cutting criterion
Process discipline	Very important	Cross-cutting criterion	Important
Degree of control over product specification	Important	Cross-cutting criterion	Important
Market potential	Very important	Cross-cutting criterion	Important
Product line awareness	Desirable	Desirable	Desirable
Reuse aptitude	Desirable	Desirable Non important	Desirable Non important
Reuse potential	Very important	Between very important and important	Desirable

be desirable for an organization to have knowledge of the domain before adopting PLE, it is certainly not essential. However, Expert #7, in line with **APPLIES**, believed that this criterion is *very important*. By means of explanation, he opined that it was very important for an organization to have access to experts who know the domain of interest. While currently the *preparation assessment model* includes statements that ask, as Expert #6 suggested, if the organization already has this knowledge (Statements 10, 11, 12, 14 and 16), the *preparation assessment model* does not include statements that ask if the organization will have access to people who are experts in the domain. According to Expert #7, this is more important than having the knowledge beforehand. These results suggest, therefore, that the **domain knowledge criterion should be adjusted to include statements that will evaluate an organization's access to experts** and that **the assessment model needs to adjust the prior knowledge that an organization may have about the domain of interest to a category of *desirable***.

Finally, both Expert #6 and Expert #7 agreed that the criterion *potential products* is *important* while **APPLIES** considered this *desirable*. As mentioned previously (Sub-section 5.2.3), the experts believed that the number of potential products is important because it is a signal that may inhibit an adoption. Thus, a proposed adjustment is that **APPLIES should assign greater importance to the criterion *potential products***. Furthermore, Expert #7 stated that in addition to the number of products **it is important that these possible products are predictable**, or that it is possible to predict that there

will be reuse between one product and another, because several heterogeneous products imply overheads in their management.

- **Desirable/irrelevant criteria:** Both **APPLIES** and the two experts considered that the criteria *product line awareness* and *reuse aptitude* were *desirable* or *not important*. The former refers to the prior knowledge that people in the organization might have about product line engineering, while the latter refers to current organizational practices and traditions that favor reuse.

Additionally, Expert #8 in Evaluation #8 and Expert #5 in Evaluation #5 provided useful input to complement the analysis regarding factors that are desirable for evaluating an organization's preparedness. In particular, Expert #8 listed factors that do not represent barriers to initiating a product line approach but that could facilitate an adoption: *past experience in PLE*, *previous knowledge of PLE*, *current artifacts that could be reused in a product line* and *current organizational practices that make it easy to follow a reuse approach*. For example, it is very important that people have the time, resources and a positive attitude to learn about product line engineering, while having previous knowledge in product line engineering is desirable but not indispensable.

Some comments collected regarding the desirable statements are: *"If you don't have that you can still do it, it's just more work ... we can teach people how we differentiate common and variable features ... It's probably better if the organization has defined a process to reuse artifacts, so it's desirable ... we can manage the adoption if the organization does not have a process to define requirements ... we can teach organizations how to figure out what's reusable... If each legacy product is completely different it's very hard. But I can say that is desirable, so if an organization is motivated, they're going to have to pick one of the legacy products and then grow that to the super set,"* (Evaluation #8 - Expert #8)

"So you can always teach people changes or force people to change if they don't have the experience. So it's desirable," (Evaluation #8 - Expert #8).

"If they don't know to identify which are the reusable assets now because all their focus is on a product, we can teach them how to figure out what's reusable," (Evaluation #8 - Expert #8).

Expert #5 also considered low coupling (Statement 47) and high cohesion (Statement 48) are desirable criteria: *"The adoption of product line engineering would help decrease coupling which is good for maintenance, development, and testing regardless of whether there is product line or not. So low coupling is better but not indispensable to adopting a PLE approach,"* (Evaluation #5 - Expert #5).

Regarding documentation (Statement 35), Expert #5 indicated that agile organizations may not have formal documentation. Also, he explained that it is possible to encounter organizations that do not document the requirements (Statements 33). This could be the case for organizations that follow an agile methodology: *"If they are agile, it is possible that they do not document the requirements in documents but in the source code,"* (Evaluation #5 - Expert #5).

Previous results may indicate that the following statements included in **APPLIES** could be considered *desirable* as they evaluate desirable but not mandatory conditions to adopt a PLE approach: organizations' knowledge in the domain under evaluation (Statements 10, 11, 12, 14, 16), organizations' experience reusing artifacts (Statements 43, 44, 45), organizations' experience with product line engineering concepts (Statement 37), organizations' experience working with roles (Statement 59), existence of a shared vocabulary among people (Statement 49) and artifacts that could be reused in product lines (Statements 33, 35, 47, 48, 50, 51, 52, 53, 54, and 56).

These statements are distributed across different assessment criteria which, in turn, have been assigned different values of importance in the *preparation assessment model*: domain knowledge (5 statements), process discipline (4 statements), product line awareness (1 statement), reuse aptitude (6 statements), software engineering capability (1 statement) and reuse potential (6 statements). This widespread distribution could indicate that instead of being separated, **these statements should be organized under common criteria that would be classified as *desirable* in the *preparation assessment model***. For example, Expert #6 considers that the criterion *reuse potential* was *important*, but Expert #7 and previous results indicate that this criterion should be *desirable*.

- **Cross-cutting criteria:** a noteworthy finding of Evaluation #6 was the emergence of a new category of importance in which the experts grouped criteria that they considered important, not only for the adoption of a product line engineering approach, but across the organization. In the third and fourth columns of Table 5.1, these criteria were assigned the value *cross-cutting*. For example, in the case of the criterion *software engineering capability*, the experts explained that if an organization does not have good engineering practices to develop its products, it will have problems making one product let alone making many products. Thus, the importance of this criterion is not only associated with preparedness to adopt product line engineering but is *cross-cutting*.

Expert #6 further classified the criteria *Process discipline*, *Degree of control over product specification* and *Market potential* in this category, but Expert #7 considered these criteria as *important*. These criteria are discussed in more detail below:

For the *Process discipline* criterion, in Evaluation #6, Expert #7 indicated that he considered *process discipline* as *important* in the sense that an organization's processes should not be chaotic but repeatable; this does not necessarily imply having a structured process with some specific quality level or certification. According to the same expert, if an organization does not follow a disciplined process the key question should be: *Could the organization develop a process discipline?* as organizations need this capacity to adopt a PLE approach.

For the *Degree of control over product specification* criterion, Expert #7 explained that even if always there is a way to turn around technical constraints, it is important to consider that this lack of freedom exists. In contrast, Expert #6 felt that this criterion is cross-cutting. Expert #6's perception was confirmed by Expert #8 as he explained that at least for a feature-based PLE, adoption takes advantage of the artifacts that organizations already have and therefore even with low freedom over product specification to define the product line, adopting a PLE is still possible: "*We're using what organizations already have. They may be very constrained, but they could still do product lines. They can have a lot of freedom to adopt things and they can do a product line approach,... We don't require that people re-architect their systems to do PLE. If it's a tightly coupled mess we can still put variation points wherever we want and make it configure, so overall you want your architecture to be good with low coupling, but that has no impact on success with PLE using our technology... we don't rely on composable modular components,*" (Evaluation #8 - Expert #8).

According to Expert #6, the *Market potential* criterion is *cross-cutting* because if there is not a potential market for the products, then the organization will have a problem whether they adopt a product line approach or not. Moreover, this expert explained that *Market potential* could be evaluated, in the case of product line engineering, through the potential products. In contrast, Expert #7 considered this criterion *important* and recommended including statements that evaluate whether reusable artifacts will have an external or internal market. According to this expert, an external market refers to whether there will be

demand for the potential products to make reuse worthwhile, whereas an internal market refers to whether the reusable artifacts can be used within the organization (*Evaluation #6 - Expert #7*).

5.2.5 Content understandability

Different clarifications were needed to explain the meaning of terms incorporated in the assessment models. For example, in *Evaluation #1*, the CEO stated: “*I think the questions are fine but there are some that need more context and others that can be separated into parts ... there are some questions that are ambiguous concerning what the people who answer them may think,*” (*Evaluation #1 - CEO*). In *Evaluation #2*, the CEO stated that “*there were some questions that were not entirely understandable,*” (*Evaluation #2 - CEO*). Also, in *Evaluation #3*, one of the participants said: “*there are some questions that could be explained in more informal terms to make them simpler,*” (*Evaluation #3 - Open Questions*). Two participants also expressed that they had difficulties understanding the content included in the *motivation assessment model* (see [Table B.20](#)): “*In the weaknesses is where perhaps there were more ambiguities in our case,*” (*Evaluation #2 - CEO*); and “*I felt a bit lost answering the questions about motivation as they leave room for doubts and can be misinterpreted,*” (*Evaluation #4 - Open Questions*). [Table B.20](#) presents the complete set of comments.

The results from the questionnaire used in *Evaluation #4* show that both assessment models require adjustments to make their content more understandable, because although there were scores of four and five, there were also scores of two for both assessment models which is below the minimum expected performance (see [Figure 5.5](#)).

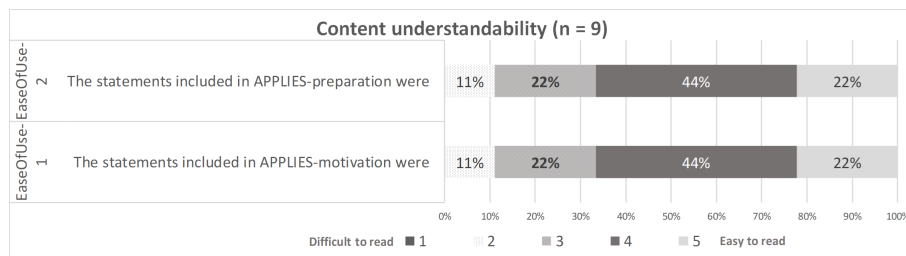


Figure 5.5: Frequency chart: answers collected from questionnaire presented in [Table B.6](#). [Table B.9](#) presents the frequency, minimum and maximum value found in the responses, as well as the summative results for each factor of analysis.

Problems with clarity of wording were the most common defect found in the content⁴. Both evaluation models received adjustments at the end of the first evaluation round to fix the clarity of wording issues. For instance, the statement “*The individuals would be committed to try product line engineering methods,*” was changed to “*Individuals would be willing to try new techniques, tools or ways of doing things,*” and the statement “*The product line project will have a ‘product line champion’ or ‘angel’ at a high level of the hierarchy,*” was changed to “*The product line project would have a project leader with authority to make decisions and support the idea of change.*” [Tables B.3](#) and [B.4](#) in [Appendix B](#) present the adjustments made in the two assessment models before starting the second round of evaluation. However, not all the defects identified in the first round of evaluation were corrected, as in some cases it seemed prudent to collect more evidence before making adjustments. Generally speaking, problems with understandability related to the use of technical terms which were not understood by those carrying out the evaluation, such as *core assets*, *artifacts*, *potential products*; unnecessary use of synonyms such as: *organization*, *company*, *enterprise*, *business unit*; and phrases that could be simplified were the reasons

⁴Subsection [5.2.2](#) explains other defects related to content pertinence

that explain the problems that limits the clarity of wording.

More in particular, referring to the statement on technological stability, Expert #2 recommended clarifying what is meant by technological stability: “A new version of Java will be released every 6 months. Angular major versions are released every 6 months. Are they non-stable technologies?” (Evaluation #5 - Expert #2).

One aspect that was not taken into account in the design but could affect understandability of the content is that **APPLIES** might need inputs from people with different profiles. One participant in Evaluation #3 thought that any person who knows the organization could answer the statements that **APPLIES** includes “Anyone who knows the organization, even without technical knowledge can answer the questions,” (Evaluation #3 - Open Questions). However, comments collected in Evaluations #1, #3, and #4 contradict this idea as they indicate that **APPLIES** needs inputs from different stakeholders with knowledge of different aspects of the organization. For example, some questions require responses from people with a technical background, while others might require input from people familiar with the organization’s operation and still others would need knowledge of finances. Considering these contradictory comments, the resulting finding is that both positions could be true because **APPLIES** includes questions related to technical and managerial topics. It is possible, in small organizations, that the information required could be known by only one person, or be distributed among different people. **The most important thing is that people conducting the evaluation understand the factors under evaluation and that the organization can provide the requested information regardless of whether the information comes from one or more respondents.** Table B.22 shows the comments collected related to this finding and some illustrative quotes are presented below:

“It is important to take into account that depending on the stakeholder who is using **APPLIES** there are factors that may be less relevant or even not applicable. For example, if someone from the technical area is using **APPLIES** it is possible that they are not interested in the financial evaluation ... If we look at the management level some opportunities and weaknesses can be seen from one perspective, but if we look at the technical level opportunities or weaknesses can be seen from a different perspective,” (Evaluation #1 - CEO).

“Some questions can only be answered by someone who is in the area of development,” (Evaluation #3 - Open Questions).

“Questions included in **APPLIES** are management-oriented. For example, developers do not necessarily have details about how the organization deals with customers,” (Evaluation #3 - Open Questions).

Involving different stakeholders was useful to encounter different defects in the content of **APPLIES**. For example, some statements that were clear to academic experts were confusing to people without prior knowledge of product lines. This is the case, for example, with Statement 33: *there is potential to create at least three different products that share common functionalities*. This statement was improved after the first round of evaluation, but the text was still unclear to some participants from Evaluation #4.

Another finding was that in order to use **APPLIES** it is important for organizations to have defined the domain for which they might consider adopting a product line engineering. This finding emerged from the experience with Evaluation #2. The organization that participated in Evaluation #2 builds and maintains tailor-made software, i.e, the organization does not have a main software product that is commercialized for different clients, nor a specific market domain in which it limits its services. During Evaluation #2, participants had multiple doubts about statements that used terms such as domain or potential products. Many of these doubts could have been avoided if the domain of interest had been clearly defined before starting the evaluation with **APPLIES**.

Finally, while specialized or in-depth knowledge of product line engineering is not required to conduct

the evaluation, it is essential that users know at least what product line engineering is, what benefits and disadvantages are inherent, and the meaning of specific terms such as variability, commonality or reuse. Two comments collected in this regard were received:

*“I have a technical background, so in general I understand the concepts included in **APPLIES**, but I am not sure the language is clear enough for other types of stakeholders ... If **APPLIES** is completed before the person knows about product lines in depth then some statements would require more explanation, such as those referring to specific terms like variability or commonality,” (Evaluation #1 - CEO).*

*“If some manager has no idea about PLE, then this person would not understand any questions. In contrast, if the users of **APPLIES** are people with understanding in the area there would be no problem,” (Evaluation #3 - Open Questions).*

5.2.6 Content - recap

- **The *motivation assessment model* needs content adjustments to assist **APPLIES** users to identify the reasons that could motivate an organization to adopt a PLE approach.** While some of the adoption drivers included in the *motivation assessment model* are relevant, others are less useful to help organizations differentiate between reasons for adopting a PLE approach, and reasons for not doing so.

The adjustments that need to be made relate to the following:

- Not all adoption drivers included in **APPLIES-motivation** are oriented towards identifying whether the organization has problems that need to be solved. As mentioned in the previous findings, some of the adoption drivers do not have the power of discrimination expected and some overlap. The adoption drivers, therefore, should be refined to include only problems that can be solved by adopting product line engineering.
- The evaluation of motivation should consider both the importance and the urgency of the problems that need resolving, as these two aspects could lead people in the organizations to drive the adoption of a PLE approach.

The lack of relevance of the adoption drivers is an important issue because the purpose of **APPLIES-motivation** is to identify the extent to which the needs of an organization are aligned with objectives that PLE could tackle. Therefore, irrelevant adoption drivers could be misleading: organizations could answer ‘yes’ to some of the questions included in **APPLIES-motivation** leading them to believe that they have motives to adopt a PLE approach when, in fact, they do not.

- **The *preparation assessment model* includes relevant criteria that allows **APPLIES** users to identify how prepared organizations are to adopt a PLE approach, but needs adjustments to remove, modify and add statements that may improve the relevance of the evaluation results.** The positive findings in **APPLIES-preparation** indicate that most of the topics included in the *preparation assessment model* are relevant for identifying how prepared an organization is to adopt a PLE approach. However, there are additional topics to consider in the assessment model and some statements to remove and adjust, either to avoid bias in the responses or to provide clarity for potential users of **APPLIES**. Finally, the importance assigned to some of the criteria by **APPLIES** should be adjusted to bring them in line with the levels of importance assigned by the experts. Based on the findings presented through this Section (Section 5.2), Tables 5.2, 5.3, 5.4 and 5.5 summarize respectively the factors to maintain, remove,

modify and incorporate into the *preparation assessment model* and identify the statement ID numbers related to these factors.⁵

Table 5.2: Summary of factors to maintain in the *preparation assessment model*

	Related assessment criterion	Factor	Statement ID # (see Table B.4)
Operational	Commitment of key actors	Top manager support	1
		Adoption leader	2
	Degree of control over product specification	Control over product specification	7, 8
		Existing products in the domain	10, 11, 12
	Domain knowledge	Knowledge and experience in the potential domain	14, 16
	Market potential	Future market for the products	22
	Openness	Staff openness to change	23, 24, 29
	Organizational willingness	Willingness to do organizational adjustments	26
		Staff experience in collaborative work	27
	Potential products	Potential to create at least three products	30, 31
		Domain stability	32
	Process discipline	Documentation	33, 35
		Organizational experience following a systematic process	34
Product line awareness	Existence of maintenance plans	36	
	Previous knowledge in PLE	37	
	Willingness to learn PLE concepts	37	
	Willingness to provide infrastructure, training materials	38	
	Willingness to assign people to the adoption initiative	39	
Technical	Commonality and variability	Common and differentiating features	40, 41, 42
		Reuse aptitude	43, 44, 45, 46, 47, 48, 49
	Reuse potential	Existing artifacts that could be reused in a product line	50, 51, 52, 53, 54, 56
	Software engineering capability	Configuration management practices	57
Existing organizational roles		59	
Economic	Readiness to invest	Resources availability	64
	Readiness to pay migration costs	Organizational willingness to pay the cost of adopting a PLE approach	66, 67
		Organizational willingness to pay maintenance costs	65

⁵In this document, “factors” refers to the broad topics under evaluation. **APPLIES** operationalizes the factors into criteria which, in turn, are broken down into statements. Tables relate the statement ID numbers to the factors in order to facilitate mapping between each factor and its corresponding statements, thus facilitating adjustments in terms of incorporating, maintaining, adjusting or removing statements in **APPLIES**.

Table 5.3: Summary of statements to remove from the *preparation assessment model*

Statement ID # (see Table B.4)	Topic	Explanation
58	Strong software engineering capability	This statement was evaluated concretely in other statements
3, 4, 5, 6	Customer connection	
9	Capacity to offer products that the market has not anticipated	Those statements are not decisive factors in considering the adoption a PLE, instead they could be an advantage for any type of project
17, 18	Being among the market leaders	
61	The use of proprietary tools	
60	Competence in the technology for implementing the product line	Those statements are difficult to evaluate at the <i>initiation phase</i> of the decision process as they require deeper analysis and experience in adopting a PLE approach
62	Expected ROI	
63	Maintenance cost with and without PLE	

Table 5.4: Summary of factors to modify in the *preparation assessment model* of **APPLIES**

Adjustment	Explanation	Statement ID # (see Table B.4)	Source
Consider whether an organization's has maturity to follow a repeatable process	Instead of asking for a particular CMMI level, the statement should ask about an organization's capacity to produce products in such a way that the process is not chaotic but repeatable	34	(Evaluation #7)
Technological stability	Clarifying what is meant by technological stability	32	(Evaluation #5)
Extend statement related to organization's willingness to pay the cost of adopting a PLE approach	Incorporate statements that ask for the organizational willingness to pay for other costs involved in the adoption. Some of those costs appear due to activities such as performing the commonality/variability analysis, defining what products will constitute the product line, identifying the variability points, designing and developing the reusable artifacts, etc.	67	(Evaluation #5)
Unify statements that evaluate economic conditions	Unify under the same criterion the statements included in the <i>readiness to invest</i> criterion and the <i>readiness to pay migration costs</i> criterion	65, 66, 67	(Evaluation #6)
Unify statements that evaluate commitment of key actors	Unify under the same criterion statements included in the <i>commitment of key actors</i> criterion and the <i>organizational support</i> criterion	1, 2, 26, 29, 27	(Evaluation #6)
Unify statements that evaluate commitment of key actors	Unify under the same criterion the statements included in the <i>commitment of key actors</i> criterion and the <i>organizational support</i> criterion	1, 2, 26, 29, 27	(Evaluation #6)

Table 5.5: Summary of factors to incorporate into the *preparation assessment model*

Factor	Explanation	Source
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Customer readiness	It is important to consider from a business perspective whether customers who receive the products would be willing to accept the implications of adopting a PLE such as continuous updates or a shared base of artifacts such as source code, designs, tests, etc.	(Evaluation #7)
Use of testing practices	Configuration management practices and testing are good indicators on how healthy organizations are, so they can embrace the challenges that adopting a PLE approach implies. If there is not enough maturity in the organization in terms of engineering, product line engineering amplifies previous problems instead of solving them. For example, a bug can creep up in more than one product at the same time if an organization don't test well	(Evaluation #7)
Support from technical leaders	The support from somebody that is respected and trusted from the technical point of view is important to gain the confidence that could inspire the technical team to trust in the the adoption of a PLE approach.	(Evaluation #7)
Predictability of potential products	Besides the number of products it is important that these possible products are predictable, that is to say that it is possible to predict that there will be reuse between one product and another because many heterogeneous products imply overheads in their management.	(Evaluation #6)
Access to domain experts	Having access to experts who know the domain of the product line is important to define the portfolio of products that will be part of the product line. In the evaluation of the preparedness is more important having access to those experts than having the knowledge beforehand.	(Evaluation #6)

- [Content understandability] People with a basic knowledge of PLE were able to understand the content included in **APPLIES**, but some improvements are needed. The *motivation assessment model* and the *preparation assessment model* were sufficiently understandable for people to use **APPLIES** to conduct the evaluation, but both assessment models require adjustments to make their content more understandable. Additionally, it should be clarified that **APPLIES** may need inputs from people with different profiles, or that, collectively, the team members should have sufficient expertise to answering the full set of questions included in **APPLIES**.

5.3 EQ3 - To what extent do users perceive the **APPLIES** framework as useful and why?

This section presents the findings regarding the perceived usefulness of **APPLIES**. These findings are the result of the analysis of the closed and open-ended questions of the satisfaction questionnaire introduced in Chapter 3, as well as the analysis of transcripts from Evaluations #1, #2, #3, #5 and #8. Correspondingly, this section first presents the results of the closed-ended questions of the satisfaction questionnaire, followed by the findings obtained from the open-ended questions and transcripts.

The results collected from the satisfaction questionnaires show that the majority of participants reported that **APPLIES** provides useful information to justify the adoption (or not) of a PLE approach in an organization: 19 of 25 participants seemed to believe that **APPLIES** is useful to justify a decision, as they responded with a score greater than, or equal to four ($score \geq 4$). Twenty of 25 felt that **APPLIES** provides information on preparedness, and 20 of 25 felt that it helps to evaluate an organization's motivation. Most of the respondents were satisfied with **APPLIES**, as 22 of 25 responded with a score greater or equal to four ($score \geq 4$) (see Figure 5.6).

The comments collected from the qualitative sources explain the usefulness of **APPLIES** for three purposes:

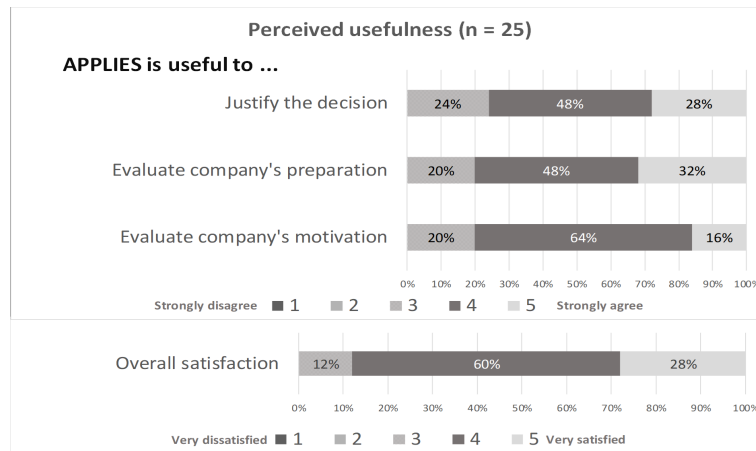


Figure 5.6: Frequency chart: responses collected from the questionnaire in Table B.5 about perceived usefulness and intention to use **APPLIES**. Table B.8 presents the frequency, minimum and maximum value found in the responses, as well as the summative results for each factor of analysis.

(i) to identify an organization’s conditions for adopting a PLE approach; (ii) to detect what factors should be improved for adopting PLE; and (iii) to provide insights into what to consider before adopting a product line engineering approach. Table B.24 provides the full set of quotes supporting these three purposes.

- i **APPLIES helps people to identify an organization’s conditions for adopting PLE.** For example, the CEO who participated in Evaluation #1 agreed that the results provided by **APPLIES** described the reality that the organization experienced before starting a product line engineering approach (this evaluation was retrospective as the organization had already adopted PLE). At that time, the decision was inspired more by what the organization could gain rather than a systematic analysis of the motives and the conditions to carry out this change. In this regard, the CEO also said that **APPLIES** could help people to think about “*things that could be important, but that you only discovered because the APPLIES framework asked about them,*” (Evaluation #1 - CEO).

Similarly, participants from the organization with no experience in product line engineering agreed that the results identified by **APPLIES** provided a snapshot of the organization’s situation for initiating a product line engineering approach. For example one of the participants noted, “*It seems to me that the map and the questions place us in the weak points that need to be attacked and in the strength that we would have. It gives us a panorama that seems clear to me of the current situation to initiate a product line engineering approach,*” (Evaluation #2 - Leader of Knowledge Management).

Similar comments were received from participants in Evaluations #3 and #4:

“*It provides useful information about the current state of the organization,*” (Evaluation #3 - Open Questions).

“*I feel confident because the questions that are asked lead to a very good questioning about the current state of an organization,*” (Evaluation #4 - Open Questions).

- ii **APPLIES is useful to detect what factors should be improved for adopting PLE.** When the organization in Evaluation #1 decided to adopt PLE, the decision was inspired more by what the organization could gain than by a systematic analysis of the reasons and conditions for making this change. In this regard, the CEO said that **APPLIES** showed factors that were important for his organization in adopting product line engineering, “*It helps me because there are issues that you perceive need to be*

improved but you do not know what they are. With this tool it is possible to identify those issues, and it becomes something more objective and measurable.... from the technical dimension, it shows where you need to improve or where you are weak,” (Evaluation #1 - CEO).

Similar comments were received from participants in Evaluations #2 and #3:

“Filling out these statements gives us insight into what things you need to be aware of when adopting a product line engineering approach,” (Evaluation #2 - Leader of Innovation).

*“**APPLIES** is a good guide for transforming the organization because it gives me the basis for identifying what things I should start focusing on to bring the organization to the point where it is ready to adopt the PLE approach,” (Evaluation #3 - Focus Group).*

Also, the participants who used **APPLIES** to perform an independent evaluation (Evaluation #4) stated that **APPLIES** helped them to identify the weaknesses of the organizations they evaluated, which helped them to provide recommendations. Some illustrative quotes of this are:

“I managed to obtain the weaknesses that the organization has, and from this I had a basis to define what was right for the organization,” (Evaluation #4 - Open Questions).

“It gives a good idea of what factors are positive and negative for implementing PLE. An analysis can be made from these results,” (Evaluation #4 - Open Questions).

“It shows where the mistakes are and how they could be tackled,” (Evaluation #4 - Open Questions).

Finally, one of the academic experts stated that **APPLIES** could help organizations identify what they should consider when they are preparing to adopt a PLE approach: *“**APPLIES** seems very useful to me because it tells organizations what they need to improve in order to be prepared to adopt product line engineering, which is basically solving weaknesses and threats if any,” (Evaluation #5 - Expert # 3).*

- iii **APPLIES provides insights into what to consider before adopting PLE.** Participants from Evaluation #3 stated that **APPLIES** offered them guidance on what to evaluate before adopting a product line engineering approach. For example, one of the participants stated: *“**APPLIES** gives me an outline of what questions to ask or in which direction to conduct the interview,” (Evaluation #3 - Open Questions).* Similarly, another participant said *“Implementing PLE involves many things and **APPLIES** allows one to limit the questions that one should ask,” (Evaluation #3 - Open Questions),* while another participant stated: *“**APPLIES** offers an abstraction of the essential factors to consider in order to implement or reject a PLE,” (Evaluation #3 - Open Questions).*

APPLIES could be useful as a starting point for further analysis before a decision is made, and in some cases could provide enough information to make a decision, but this is not necessarily true in all cases. In this regard, different points of view were identified. Some participants considered that **APPLIES** does not provide enough information to make a decision regarding adopting PLE, while others believed that it does (see Table B.23). For example, one participant said: *“The information I received from **APPLIES** does not give me enough confidence to conclude that an organization is motivated or prepared to adopt a product line engineering approach,” (Evaluation #4 - Open Questions)* whereas another said *“It is difficult to evaluate whether it is feasible or advisable to use PLE in an organization, and **APPLIES** makes it easier to make this decision,” (Evaluation #3 - Open Questions).* In the middle of both sides, other comments indicate that **APPLIES** provides useful information to support a decision, although this information is not necessarily enough to make a decision regarding the adoption of the PLE (see Table B.23). For example, one participant said: *“I would recommend it for a quick study of the possibilities of integrating PLE in an organization, it generates notions but not determinant information,” (Evaluation #3*

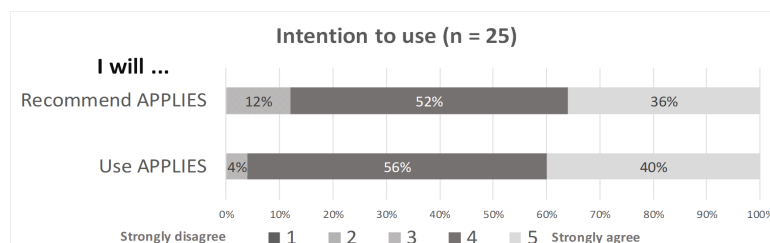
- Open Questions). Similarly, another respondent commented: “The information I get from **APPLIES** is not enough to make the decision, I would say I want to know more things, but the good thing is that **APPLIES** gives you insights about where you need to analyze in more detail. For example, in our case we have to confirm if the percentage of reuse is as high as we expect,” (Evaluation #2 - Leader of Innovation).

One of the industrial experts pointed out that people use data as an excuse to support or reject a decision they have already made, which could limit the interest in using a solution like **APPLIES**: “What you often see is that there are two groups in the organization, the group that wants to do this... they want to get into product lines and the group that doesn’t want to get into product lines and they want to keep things as they are. Both use data to justify their position, both parties use the data available and interpret it in fundamentally different ways in order to support their viewpoints...decision-making is actually not rational but is very often driven by politics and by personal context, personal networks... this is what makes it so difficult,” (Evaluation #7 - Expert # 10).

APPLIES does not aim to respond directly to the question of whether or not to adopt a product line engineering approach, but rather to provide information that will assist people in making this decision. Indeed, human beings are not cold and calculating information processors (Mu & Pereyra-Rojas 2017) and therefore factors such as the time available to analyze the decision, resources to be invested in the analysis, or the attitude and prior beliefs of the decision makers could influence, on the one hand, the decision making process and, on the other hand, the decision and its outcome (Ariely 2008, Pohanková 2010, Mu & Pereyra-Rojas 2017). **APPLIES** has considered these limitations which is why it does not attempt to replace decision-makers. Instead, its purpose is to provide information that could be useful to reduce bias and strengthen the arguments that support any decision regarding the adoption of the PLE. Thus, even if people just use the information to defend the arguments they previously had in mind, information that comes from a systematic review rather than subjective appraisals is still an important contribution that can reduce the uncertainty of the decision.

5.4 EQ4 - Would the practitioners use **APPLIES** themselves? Why or why not?

The evidence collected from the satisfaction questionnaire shows that **the respondents who answered the questionnaire intend to use APPLIES in the future**. According to the results presented in Figure 5.7a, almost all the participants would recommend (24 of the 25 responses) or use (22 of 25) **APPLIES** themselves in the future ($score \geq 4$).



(a) **APPLIES**

Figure 5.7: Results satisfaction questionnaire about the intention to use Frequency chart: responses collected from questionnaire in Table B.5. Table B.8 present the frequency, the minimum and the maximum value found in the responses, as well as the summative results for each item of analysis.

Furthermore, the qualitative evaluation illustrated that participants believed that **APPLIES** provides useful information and that they would recommend **APPLIES** to the audience **APPLIES** aims to support,

people interested in evaluating the convenience of adopting a PLE approach. In particular, Table B.25 shows comments collected through the questions *why or why not would you use APPLIES?* and *why or why not would you recommend APPLIES?* The comments overall show that the participants had a positive perception of APPLIES. For example, one participant said “*I would use it ... I think APPLIES is something good that can be recommended...I think it’s cool and interesting,*” (Evaluation #1 - CEO).

In addition, three comments were received regarding what kind of organizations participants would recommend APPLIES to. For example, one participant said: “*I would recommend it to organizations that want to evaluate whether it is worthwhile to implement product lines backed by a tool,*” (Evaluation #3- Open Questions).

Perhaps as a **limitation** of the results detailed above, some people said they would recommend APPLIES because they do not know any other solution with the same purpose and capabilities. For instance one participant in Evaluation #3 said: “*I would recommend it, as I have not seen another tool capable of giving a prior analysis of the feasibility of adopting PLE,*” (Evaluation #3 - Open Questions) and another participant said: “*It’s a solid basis for decision making, and it’s the only one I know,*” (Evaluation #3 - Open Questions).

It may be important to consider that a lack of other solutions similar to APPLIES could bias participants’ responses, as they would be willing to use the available solution, but this does not necessarily indicate that APPLIES is the best solution for them. Until now, APPLIES has been evaluated to identify its strengths and weaknesses in relation to its objectives (which is known as absolute evaluation (Scriven 1991)) and not its strengths and weaknesses compared to other proposals (which is known as relative evaluation (Scriven 1991)). Thus, the results obtained for intended use do not take into account that participants might prefer other approaches to APPLIES. In order to strengthen the evidence, a future evaluation could be designed in which participants interact with APPLIES and with an approach similar to APPLIES during the same evaluation. Transit-PL (Tüzün et al. 2015) could be used for this comparison because, on the one hand it satisfies similar requirements to APPLIES, and on the other hand it uses a self-evaluation strategy to capture the data as APPLIES does.

Two other findings related to the intended use of APPLIES emerged from the analysis: (i) APPLIES is not mature enough to be included in vendor websites of commercial tools; and (ii) a high price could limit the use of APPLIES. Both findings are explained below:

- **APPLIES is not mature enough to be included in vendor websites of commercial tools.** An industry expert indicated that there is value in what APPLIES proposes and that it is a good extension to the field, given that a good PhD builds on and extends existing knowledge. However, according to this expert APPLIES is not yet reliable enough for commercial production: “*We would see it as a risk if we put it up on the website, somebody that would normally come talk to us would say ‘I did the evaluation and I self-assessed that it is not useful to my organization’. That’s not to say that the work is not useful, I think it’s a good extension to the field; a good Ph.D takes knowledge and extends it one step further, but that doesn’t mean that it’s ready to go on a commercial tool vendor’s website,*” (Evaluation #8 - Expert # 8).

This reflection is consistent with the state of maturity of the project. APPLIES is a developing initiative that requires improvements and evaluations that will contribute to its maturity and stability.

- **A high price could limit the use of APPLIES.** The industrial practitioner that participated in Evaluation #1 indicated that the only factor he believes could discourage the use of APPLIES in the decision-making process would be if APPLIES were priced beyond what organizations could afford: “*One factor would be perhaps the economic aspect: in case APPLIES becomes very expensive,*” (Evaluation #1 - CEO). However, as APPLIES was conceived as a free initiative pricing should not be an obstacle for its

use.

5.5 Summary of Chapter 5: Evaluation results

This chapter responds to four of the five evaluation questions (EQ1 to EQ4) introduced in Chapter 3 to evaluate **APPLIES** in terms of its ease of use, content pertinence, perceived usefulness and intention to use. The findings presented throughout this chapter are summarized as follows:

- *EQ1 - To what extent do users perceive **APPLIES** as easy to use and why?*

In terms of positive results, all practitioners who used **APPLIES** (Evaluations #1 to #4) are able to evaluate for themselves an organization's motivation and preparedness for adopting a PLE approach. The closed response format is found to be a useful design decision in the operationalization of the evaluation, as participants are familiar with this type of format and know how to use it. Furthermore, participants find the charts to be a useful way of presenting results. Finally, participants from Evaluations #1, #2, and #3 are able to complete all the assigned tasks with no critical errors using the tool that **APPLIES** provides, under the supervision of the researcher. Overall, no comments are received indicating difficulties with using the tool that operationalizes **APPLIES**.

In terms of adjustments that could be helpful to improve ease of use, the Likert response format performs better than the binary response format, as it increases respondents' options. In addition, it is found that the Likert response format should include an intermediate option between "agree" and "disagree" (different from the "don't know" option) to broaden the set of possibilities and a first adjustment to incorporate this intermediate option took place in **APPLIES** Version 2 with promising results. Another result to consider is that the response formats should provide more information and guidance to help **APPLIES** users identify the most appropriate response for their case. Finally, the adoption drivers might have different levels of importance or urgency for different organizations, so the response format should incorporate options to indicate these differences.

- *EQ2 - To what extent is the information included in **APPLIES** sufficient to evaluate the convenience of adopting a PLE approach?*

The idea of breaking down the evaluation of motivation into smaller factors is novel in the field of PLE, as this construct is not easily operationalized in terms of just one observable behavior or question. In overall terms, the perceived usefulness of **APPLIES-motivation** is high (see Figure 5.6). However, there is evidence of some cases where participants are not convinced about adopting PLE regardless of the adoption drivers selected. Thus, while **APPLIES-motivation** provides an initial base to operationalize the evaluation of motivation, there is still work to do to improve **APPLIES'** capacity to determine reasons that could motivate an adoption.

Results indicate that **APPLIES-preparation** achieves its purpose as it is able to assist users in identifying how prepared an organization is to adopt a PLE approach, for example, by identifying potential barriers that would limit an organization's ability to adopt PLE. Furthermore, the majority of the statements initially defined in the *preparation assessment model* are considered relevant for evaluating an organization's preparedness to adopt a PLE approach (see Table 5.2).

The evaluation of **APPLIES** is, in itself, considered successful as the data indicated which statements should be removed and which statements should be adjusted, either to avoid bias in the responses or to improve clarity of wording. Tables 5.3 and 5.4 concisely present the factors that need to be removed and adjusted respectively. In addition, Table 5.5 presents new factors to include in the *preparation assessment*

model. These factors might be operationalized in the future with one or more statements.

Two final points should be considered when making future changes to the instrument: (i) technical terms should be avoided and terminology should be unified when re-writing statements in the future; and (ii) it is essential to consider the knowledge and experience of potential users of **APPLIES** in order to avoid asking for information that requires deeper analysis and experience in PLE.

- *EQ3 / EQ4 To what extent do users perceive the **APPLIES** framework as useful and why? and Would the practitioners use **APPLIES** themselves? Why or why not?*

The results obtained regarding the perceived usefulness and intention to use are promising. The satisfaction questionnaire shows a high percentage of responses with scores of four or more (on a scale of 1 to 5) concerning overall satisfaction with and usefulness of **APPLIES**. In addition, the results show a high percentage of responses with scores of four or more regarding potential use and intention to recommend **APPLIES**. Along the same lines, qualitative evidence indicates that **APPLIES** is aligned with its purpose: it serves to identify an organization's current conditions with regard to adopting PLE, helps to identify which factors an organization needs to improve to prepare itself for adoption, and provides information on the factors that an organization should consider before adopting a PLE approach. Another positive result regarding the perceived usefulness and intention to use is that none of the sources consulted indicated that a solution such as the one **APPLIES** proposes would be unnecessary or useless for newcomers. While these results are positive, **APPLIES** is an open-source initiative still under development. Consequently, it is not mature enough to be included, for example, on commercial tool providers' websites.

The above results indicate that, in principle, **APPLIES** is perceived as easy to use, useful and that the participants in the study people would consider using it themselves. These results are promising, considering that **APPLIES** is a first attempt to create an approach oriented to newcomers to PLE and is still a version in progress.

Perhaps the most valuable outcome from the entire evaluation process is the identification of recommendations that could help to refine **APPLIES** further. The next chapter presents these recommendations.

Towards an evolved version - recommendations

This chapter presents recommendations to consider for a subsequent version of **APPLIES** regarding its design (Section 6.1) and functionalities (Section 6.2). The information presented in this chapter is the result of the researcher's analysis and reflection on the results reported in the previous chapter. It also considers recommendations collected from the participants of the evaluations. This chapter therefore responds to the last evaluation question introduced in Chapter 3: *EQ5 - What additions or modifications could improve **APPLIES**?*

6.1 About the design of **APPLIES**

As in Chapter 4, this section organizes the recommendations according to the three levels of **APPLIES**: *conceptualization* (sub-section 6.1.1), *operationalization* (sub-section 6.1.2), and *implementation* (sub-section 6.1.3).

6.1.1 Conceptualization

As mentioned in Chapter 4, the *Conceptualization* level provides the conceptual basis for defining *what should be evaluated?* in terms of an organization's motivation and preparedness for adopting a PLE approach. This section, thus, introduces recommendations to improve the two assessment models that constitute this level: the *motivation assessment model* (see sub-section 6.1.1.1) and the *preparation assessment model* (see sub-section 6.1.1.2).

6.1.1.1 Motivation assessment model

Three lessons were learned with respect to the current version of **APPLIES-motivation**:

- i **APPLIES-motivation** should change its focus from assisting people to identify strengths, weaknesses, threats, and opportunities in an organization to assisting people to identify problems. In the current version of **APPLIES**, **APPLIES-motivation** assists organizations to recognize motives for adopting a PLE approach by identifying strengths, weaknesses, threats and opportunities. However, the results suggest that the adoption drivers in the weakness and threat categories may be more relevant to the evaluation than the adoption drivers in the strength and opportunity categories. The latter were included because they are motivating factors that could make a PLE adoption more attractive, but the findings and recommendations from experts suggest that what actually motivates organizations to initiate change are problems that limit their goals.
- ii **The problems that the assessment model helps to identify should be solvable by using a product line engineering approach.** Including extraneous factors that are not solvable by adopting a PLE approach only, as **APPLIES** currently does, is problematic because this could lead to erroneous

results that suggest that there are reasons to adopt a PLE approach when this is not the case. This finding was discovered thanks to the broad spectrum of stakeholders involved in the empirical evaluations. For example, in the case of Evaluation #2 and some organizations in Evaluation #4, the organizations were not clear about their domain or interest or did not have an obvious problem. These characteristics revealed the weaknesses in **APPLIES-motivation** to detect cases where there was no reason to adopt a PLE approach.

In order to improve the ability to discriminate, an alternative is to include only those problems faced by organizations which, based on reported experiences, product line engineering can help solve. As a preliminary step towards adjusting the adoption drivers, papers reporting industry experiences in the adoption of product line engineering were reviewed to identify the root causes of the adoption. This review established that the duplication of tasks and the complexity of managing variability in the product portfolio were two problems that a PLE approach could help to solve.

iii **APPLIES-motivation** should also assist people in organizations to identify the level of motivation (urgency) of an organization to address problems that a PLE approach could solve. The current version of **APPLIES** does not use any strategy in the adoption drivers to identify the urgency of problems an organization may face. A model that could serve to address this need is the Trans-Theoretical Model, also known as TTM (Prochaska & Velicer 1997). The TTM describes change in individuals as a process with six stages: precontemplation (“not ready”), contemplation (“getting ready”), preparation (“ready”), action, maintenance, and termination. For example, by adapting the first three stages from this model, **APPLIES-motivation** could help to evaluate how motivated an organization is to initiate a change innovation such as PLE. The following is an adaptation of the first three stages of the TTM that could be incorporated into **APPLIES**:

- **[Unmotivated adopter] Precontemplation:** an organization at this stage has not found any reasons to adjust the way it develops its products and has no intention to start any adjustment in the future. People have no interest in introducing a change.
- **[Partially motivated] Contemplation:** the organization recognizes that there are problems, knows what they are, and is thinking about how to solve them, but is not yet committed to taking action.
- **[Motivated adopter] Preparation:** An organization at this stage is aware of its problems and is seriously considering introducing a solution.

Table E.1 in Appendix E presents a first proposal for the *motivation assessment model* that takes into account the lessons learned above. This version of the model includes only those problems that could be directly solved by adopting a PLE approach: duplicating efforts and managing variability inefficiently. The idea of including only these types of problems is to improve the power of the *motivation assessment model* to discriminate motivation related to issues that could potentially be resolved by adopting a PLE approach; thus, should organizations proceed with adoption they would have more clarity on which issues could be improved. In addition, instead of listing all possible problems that could occur due to duplicated efforts or inefficient management of variability, the model provides examples of possible problems which people in the organization could use to identify their own conditions. This strategy avoids deficiencies in the assessment model due to unintentionally interrelated questions and incompleteness.

Furthermore, this new version also asks respondents to identify the consequences of existing problems and the importance of these. Finally, it includes a simple response format where respondents are asked to assign values of urgency to their existing problems. Based on the responses collected, the organization is then classified as an unmotivated adopter, a partially motivated adopter or a motivated adopter.

6.1.1.2 Preparation assessment model

The findings from the evaluations suggested that many of the factors covered in the *preparation assessment model* were relevant to the evaluation, but this assessment model needs adjustments to (i) reorganize its content; (ii) avoid response bias in the content; and (iii) improve the understandability of the content. Below, these adjustments are discussed:

- i **Reorganize the content.** Organizing the factors under evaluation into a hierarchical structure allows users to identify where their organization performs well or poorly. Thus, subsequent versions of the *preparation assessment model* will maintain the hierarchical structure to organize the factors under evaluation. Currently **APPLIES** operationalizes these factors into criteria which in turn are broken down into statements. However, the statements that compose the *preparation assessment model* need to be adjusted and redistributed across the criteria. Indeed, according to the findings this model has factors to remove, maintain, adjust and include (See Tables 5.3, 5.2, 5.4, 5.5). Moreover, it includes statements that unintentionally address similar factors and statements that address factors of the same level of importance but that are distributed across different criteria.

Table E.2 in Appendix E presents a first proposal that organizes the factors to evaluate across assessment criteria. This table shows the statements to keep in the *preparation assessment model*, the factors to evaluate and the assessment criteria. In this new version, assessment criteria are organized according to their relative importance. This is already defined in the current version of **APPLIES**, although the definition of each category has been adjusted as follows:

- **Very important.** These factors serve to evaluate to what extent a PLE approach is appropriate to resolve an organization's problems, bearing in mind the conditions required by a PLE approach. If these conditions are not met, a product line engineering approach is not the right alternative. This category includes criteria that are useful for evaluating whether a domain of interest has the necessary conditions to develop products using a PLE approach.
 - **Important.** These factors are related to the willingness of those involved in the adoption to adjust organizational practices and to allocate the resources that the adoption might require.
 - **Desirable.** These factors do not represent barriers to initiate a product line approach. For example, past experience or knowledge in PLE-related topics could facilitate the adoption but a lack of these factors should not necessarily motivate the rejection of PLE adoption, as long as the organization has a willingness to learn and change.
- ii **Reduce bias in opinion-related statements.** One strategy to reduce the risk of bias could be to include different roles in the evaluation and divide opinion-related questions into statements to identify: (i) whether people have previous experience; (ii) whether the respondent believes there is benefit in making the requested adjustments, and (iii) whether the respondent would be willing to modify his/her behavior. For example, to ask about willingness to make changes (see Statement 24 written as: *If needed, individuals are open to change their current practices*) statements such as the following could be added: *"New ideas are readily accepted here"*, *"I consider myself someone open to new ideas"* and *"I like the idea of learning new things"*. The first statement would be answered by managers while the second and third statements would be answered by some of the people who would be involved within the PLE adoption.
 - iii **Improve the understandability of the content.** Regarding the issue of clarity of wording, it would be useful to **avoid specialized terms about product line engineering**, as people using **APPLIES** may have only basic knowledge of this field. In addition, where specialized terms are required, a proposal

to increase their understandability is to **provide definitions and/or examples that clarify meaning**. For instance, the CEO who participated in Evaluation # 1 suggested: *It would be useful to suggest examples to help understand some questions, as the answers may depend on how well the respondent understands them and therefore it is very important that they are clear* (Evaluation #1 - Expert #1).

A similar idea emerged in Evaluations #2, #4 and #5:

*“Since the idea is that anyone can use **APPLIES** then it would be worth explaining with some example cases as well as introducing some key concepts that you can explain a priori before running the evaluation,”* (Evaluation #2 - Leader of Innovation);

“It would be good to include in the introduction to the framework a short explanation about product line engineering and an example, so users would be completely in context and during the evaluation they would not respond incorrectly due to ignorance,” (Evaluation #4- Open Questions).

“You could add examples to make sure people understand what they are responding to,” (Evaluation #5 - Expert #5)

Another proposal to increase understandability is to **unify terms**, as it was identified that the assessment models use different terms to refer to the same concepts. Current versions of the assessment models used synonyms to provide more varied texts, for example, *organization, company, enterprise* all refer to the same concept, as do *asset and artifact* and *domain and area*. However, during the evaluations it was observed that these synonyms could confuse users into thinking that these words referred to different terms.

6.1.2 Operationalization

6.1.2.1 Response format

A qualitative approach with a closed-response format is suitable for collecting evidence because it is easy to use, people are familiar with it, and it allows information to be collected quickly. However, this format is by nature subjective as the results depend on the people that provide the inputs.

The following strategies could help to avoid subjectivity when using the response format:

- **Include a multiple-choice response format** instead of a binary response format in order to provide different response options for users. The response option should consider the following aspects: it should (i) have a middle option between the extreme values; (ii) have an option for cases where the organization has no knowledge; and (iii) include an option for cases where the question does not apply to the scenario under evaluation.
- **Use the same type of response format for all parts of the framework** to reduce the learning curve for potential users.
- **Incorporate rubrics.** In order to reduce possible biases, the response format should be accompanied by an evaluation rubric to help respondents to identify the most relevant response options for their case and reduce future biases. A guide, such as a rubric¹, that generalizes the behavior observed in Evaluation #2, could lead **APPLIES** users to choose their answers from a common frame of reference, which in turn could help to facilitate consensus in the answers and reduce subjectivity.

¹A rubric is a scoring guide that enables more objective judgments about the quality of something under evaluation. Rubrics are the simplest way of synthesizing data and consist of a set of criteria plotted against levels of quality that go from excellent to poor (Scriven 1991).

The response format used in Evaluation #4 fulfilled the first three conditions described above, so the next version of **APPLIES** could use the same response format (Section ?? presents the details of this response format).

6.1.2.2 Charts

The charts used in **APPLIES** proved to be useful for summarizing the key points found in the evaluations. One lesson learned, however, is that the charts should be designed using data visualization techniques that provide more effective visual presentations. However, before making any adjustments to the existing charts, a key question to ask is: *how can the right chart be selected to transform data into an attractive and clear visual representation for a given problem?*

In particular, the purpose of representing information visually is to achieve effective communication of information, where effectiveness means: (i) clarity - the information is represented in a way that is easy to understand; (ii) integrity - the visual representation contains all the data, and nothing but the data; and (iii) attractiveness - the visual representation stimulates viewer engagement with the data (Henderson & Segal 2013). In this regard, Mackinlay (1986) propose a ranking of how best to encode quantitative, ordinal and nominal data. For example, according to Mackinlay (1986) people better understand quantitative data represented with position and length over quantitative data represented with orientation (angle). Thus, a stacked bar chart is easier to understand than a pie chart.

6.1.2.3 Evaluation process

Participants

Different people in an organization may have different information about the same factors under evaluation, depending on their roles. Indeed, involving different stakeholders in the evaluation or separating the statements by roles could improve understanding of the terms.

In the current version of **APPLIES**, the statements are the same, regardless of the profile of the people responding to them. So, it could be useful for people conducting the evaluation to share the results with others of different profiles in order to validate the answers entered into **APPLIES**. Another strategy to contrast the results is to **produce versions with different statements for different roles**. For example, to separate the statements for management and technical staff and then to provide functionalities that could compare the results. This strategy could also be useful to improve content understandability because, as mentioned before, software engineers may understand some statements that business professionals do not, and vice-versa.

In this regard, a couple of the participants in Evaluation #4 had the following observations: *“I would have liked to survey the developers in order to have a point of view that would serve to corroborate what was expressed by the development leader,”* (Evaluation #4 - Written Report)

“An evaluation of the information collected could be done with development teams to validate the information collected from the managers or area heads,” (Evaluation #4 - Written Report)

Based on the above findings, the following roles are proposed for a future version of **APPLIES**:

- *Evaluation leader*: responsible for guiding all stages of the evaluation with **APPLIES** and helping to resolve disagreements between people if they arise. He/she must be respected in the organization for his/her leadership.
- *Leaders*: have responsibilities that involve decision making, are familiar with the domain of interest and with the issues that may motivate the organization to consider adopting a PLE approach.

- *Staff*: the people who would be involved in the adoption. Technical staff such as functional analysts, developers, and testers, and support groups such as marketing, configuration management or customer support could be included in the team.

If different roles are included in the evaluation, **APPLIES** should also include a strategy to consolidate different or even contradictory opinions. Evaluation #2 was the first case in which different people from the same organization used **APPLIES** simultaneously. This way of using the framework indicated that it is important to include guidelines that lead people to reach a consensus on the answers as they may interpret the response format in different ways. For example, although all participants in Evaluation #2 answered the same questions, the responses varied on average in 50% of the cases. It was during the review of the results that a consensus was reached to define a single answer for each question.

Preparation phase - incorporate prerequisites for using **APPLIES**

An important lesson learned from the evaluations is that the target audience of **APPLIES** should be refined. In principle, **APPLIES** was intended for anyone, with some knowledge of product line engineering, interested in evaluating the convenience of adopting product line engineering in an organization. However, the results seem to indicate that **the segment of APPLIES users is more specific: people who belong to organizations that have problems managing variability and reuse, where the organization is looking for solutions to address those problems.**

In addition, potential users **need to have clarity about the domain of interest.** **APPLIES** is not useful, for example, in cases where the technical part of the product lines could be used but where there are no organizational aspects to consider. For example, when the purpose is to use product lines to automate cloud deployments, dynamic reconfigurations, etc. Also **APPLIES** is not useful if a product line is already in operation. In this case, there are other alternatives such as the Family Evaluation Framework (van der Linden et al. 2004).

A further prerequisite for using **APPLIES** is that **organizations should have already defined the domain for which they would expect to use product line engineering.**

These prerequisites should be set out in the instructions for the tool that **APPLIES** provides to be considered in the preparation phase during the evaluation process.

6.1.3 Implementation

With regard to the findings on the Excel tool provided in **APPLIES**, a limitation was that the data is susceptible to unintentional changes. Also, some participants suggested that the information could be displayed more clearly. The first problem could be corrected by blocking the cells that should not be modified and the second problem could be solved by leaving visible only information relevant to the evaluation.

Once the content of the framework is refined at the conceptual level, it would be necessary to collect responses from different cases to evaluate psychometric properties such as the reliability. This validation is important to eliminate unnecessary statements and group the questions into factors based on statistical analyses such as the Cronbach coefficient and confirmatory factor analysis². However, a difficulty the researcher anticipates with the Excel version is that each evaluation is a separate file, so in order to analyze the overall results to calculate the Cronbach coefficient, first the separate results must be consolidated but this is a time-consuming and error-prone task.

Another limitation observed by the researcher is that it would be more difficult and would require more

²According to [Hinikin \(1998\)](#) a sample size of 200 observations should be sufficient to obtain an accurate validation.

effort, to incorporate practices to improve the usability of the Excel tool than it would if the implementation were a web solution. These difficulties are due to the fact that Excel does not provide support for responsive solutions or interactive applications. For example, in Excel it is more difficult to show and hide information dynamically, to include interactivity in the charts or to show the traceability between a consolidated result and the sub-results that compose it.

However, a web solution also has disadvantages because it requires permanent connectivity to the Internet and a user risks losing the answers before seeing the results, if connectivity is missing. It would also require access to infrastructure for storing the tool and the collected responses for future analysis. Additionally, the tool would need to provide a downloadable report to save the results.

A strategy could be to continue with Excel in the early stages of the project because fewer resources are required to develop the tool and users can use it independently. Subsequently, when the content and operation of the framework is mature, a web version could be developed.

6.2 Functionalities

This section addresses adjustments related to functionalities to add (Sub-section 6.2.1) and to modify (Sub-section 6.2.2) in **APPLIES**. Furthermore, the last sub-section explains two functionalities that, although they were collected in the empirical evaluations, are not recommended for the next version of **APPLIES** (Sub-section 6.2.3).

6.2.1 Functionalities to add

6.2.1.1 Consolidate the evaluation results

It is necessary to consolidate the results that **APPLIES** delivers in **APPLIES-motivation** and **APPLIES-preparation**. This is important in order to provide the evaluators with an overall result that will assist them in determining the convenience of adopting a product line engineering approach. For example, one academic expert said,

“I would say that a general chart is missing, which indicates: “with all the above you are ready, you are not ready, you are missing 20% of your weaknesses to be ready, or something like that”. In other words, it should be possible to reach a conclusion without having to deduce that conclusion from separate charts,” (Evaluation #5 - Expert #3).

On a similar note, two other experts said,

“A final note is missing on whether or not to adopt a PLE approach... You could say something like: ‘above four, your organization could consider adopting or something like that’, or you could combine the metrics of the potential products with your results and then give the answer because you would have two metrics that support the decision... It is important that you show that the evaluation is about PE adoption, so the fact that an organization gets a 2 or 3 on the overall score is not necessarily bad, rather it would mean that the organization does not need a product line,” (Evaluation #5 - Expert #5);

“I’d rather see some metric that encompasses all of this because with the chart you can interpret it, but it would be better to define some kind of metric that encompasses all of these values and tells you whether to adopt a PLE approach or not,” (Evaluation #5 - Expert #1)

Additionally, the CEO from Evaluation #1 indicated that it would be interesting to relate the dimensions of analysis included in **APPLIES-preparation** with the evaluation of **APPLIES-motivation** to make more evident,

for example, to what extent the strengths that motivate adopting a PLE approach influence an organization's preparedness. Similarly, in Evaluation #8, Expert #8 indicated that both motivation and preparation were connected, so it would be useful if this connection were explicit in **APPLIES**: "*There is definitely a connection between motivation and preparation, so you just need to make it, then you need to connect your motivation with the ability to achieve it,*" (Evaluation #8 - Expert #8). One suggestion from this expert to encounter the connection between both aspects is to review the theory of organizational change proposed by Kotter & Cohen (2002).

A strategy to summarize the evaluation results could be to present the results of the evaluation in terms of levels of convenience, in a similar way to the approach used by CMMI. In this regard, one participant from Evaluation #3 suggested aligning **APPLIES** with maturity models such as the CMMI model. The Capability Maturity Model Integration (CMMI) is a process improvement approach that provides organizations with guidance on what should be done for each level, instead of explaining how it should be done. It proposes five maturity levels: Incomplete, Performed, Managed, Defined, Quantitatively managed, and Optimizing. This may be an interesting structure to consider for **APPLIES**.

Descriptions of four categories of adopters, inspired by the framework for *adoption of electronic data interchange* (Iacovou et al. 1995), could be used as a first alternative to classify organizations according to their maturity level for initiating a PLE adoption: *unprepared adopter*, *potential adopter*, *ready adopter*, and *unmotivated adopter*. Below are descriptions proposed for each category:

- **Unprepared adopter.** *This organization is aware of the potential benefits of PLE and its domain of interest is appropriate to consider a product line approach, but it does not have adequate performance in important factors that would allow it to integrate PLE into their operations.*
- **Potential adopter.** *This organization has needs that a PLE approach could address and its domain of interest is appropriate for considering a PLE approach, but it has limitations in important factors that could reduce its potential for conducting the adoption.*
- **Ready adopter.** *This organization has needs that could be solved with a PLE approach. The domain of interest of this organization is also appropriate for considering a PLE approach. Additionally, it has adequate performance in important factors which means it has the necessary resources to integrate a PLE approach into its operations and is willing to allocate resources to support the adoption.*
- **Unmotivated adopter.** *This organization does not recognize the need to adopt a PLE approach. It is not willing to invest resources or effort in an adoption.*

With regard to the last description, without motivation for change a transition towards a product line approach would not happen, regardless of any preparedness for that change that an organization might have. Similarly, Kircher et al. (2006) and Armenakis et al. (1993) explain that motivational forces are the key initiators of any organizational change.

6.2.1.2 Include recommendations to guide organizations.

Different comments from participants suggested that **APPLIES** could usefully extend the results with recommendations that would assist organizations to prepare themselves to adopt a product line initiative, once the evaluation is complete. For example, a participant from Evaluation #3 said: "*Instead of only presenting a numeric score, I think it would be much more valuable to offer suggestions to improve the organization's readiness for a future product line implementation,*" (Evaluation #3 - Open Questions). Similarly, another participant from the same evaluation said: "*The fact that **APPLIES** tells me that the process discipline is 1.5 doesn't tell me*

much. I would suggest rather showing it as suggestions, for example: ‘your process discipline is very low we suggest you improve in this aspect’... something more practical,” (Evaluation #3 - Open Questions)

In addition, one of the experts said: *“I think that including recommendations is interesting. For example, if you don’t have management commitment your score is low, but another outcome of **APPLIES** could be ‘ten things you need to do. One of them is go build management commitment’,” (Evaluation #8 - Expert #8).* Similarly, the innovation leader from Evaluation #2 stated: *“**APPLIES** leaves some uncertainty. If we decide that we are going to adopt the product line engineering approach then what is the next step?,” (Evaluation #2 - Leader of Innovation).* Echoing this idea, an academic expert stated: *“I find **APPLIES** useful as long as there is something behind the results. I mean, for example, in case **APPLIES** shows that an organization has a score of 4 in terms of its preparedness to adopt a PLE approach, what happens after the evaluation is done? You could put something about what comes next. Not everything, because it would be outside of the scope of your work, but something that would give organizations a guide, a plan, something to start working on later, like what the steps would be or something like that,” (Evaluation #5 - Expert #5).*

These recommendations could be built in the future, for example, based on lessons learned from experiences reported in the literature on adopting product line engineering.

6.2.1.3 Translate the instrument for non-English speaking users

Some participants recommended translating **APPLIES** from English to Spanish to facilitate its understanding. An illustrative quote on this topic is: *“There are words that due to my level of English I don’t fully understand...given that **APPLIES** is in English it is more difficult to understand for those of us who do not fully master the language,” (Evaluation #1 - CEO - Initial Version).*

Translating the instrument into different languages would help reduce the barriers of language differences and improve understandability of the content. This adjustment could be considered once the content of the assessment models no longer require changes that involve adding or deleting statements.

6.2.2 Functionalities to modify

6.2.2.1 Do not enable customization of the relative importance of assessment criteria in **APPLIES-preparation**

According to one of the academic experts, a limitation of the perceived usefulness of **APPLIES**, is the functionality offered for customizing the importance of the evaluation criteria of **APPLIES-preparation**:

“It seems to me that the relative importance should not be defined by the organization but by the product line engineering theory...the theory has certain concepts and those concepts should not change between organizations, but it is the organization that has to evaluate if they are willing to adhere to the product line engineering principles or not,” (Evaluation #5 - Expert #5).

Another expert said: *“We as product line community understand that certain things have to happen to be successful in adopting PLE, so why would you ask your potential adopters what is important or not? It’s not their choice,” (Evaluation #8 - Expert #8).*

According to these comments, the importance of the criteria in the evaluation results should represent what the PLE community considers important for successful adoption, and should not be adjusted by the person carrying out the evaluation. However, it should be noted that the *preparation assessment model* may have criteria that are not relevant in all cases. For example, statements asking about existing artifacts (Statements

47, 48, 50, 53 and 56) only make sense when organizations have already developed artifacts. An alternative to combine both cases is to predefine the importance of each criterion but include an N/A option in the response options. This would serve as an alternative in cases where the statement is not relevant for the organization.

6.2.2.2 Illustrate the economic benefits instead of asking directly for them

One academic expert stated that the usefulness of **APPLIES** could be limited by the lack of an economic analysis of a quantitative nature. According to this expert, decision makers require quantitative economic information to support their decisions:

*“**APPLIES** could be useful, but without a quantitative analysis it won’t help to make a decision, especially for the cost analysis ... in the end, the decision will be made on the basis of how much will it cost us, how quickly will the organization require the investments, how long will it take to reap the benefit and how much? Otherwise, you would have thought a little bit about it, but you’re not going to convince a cost-conscious manager without some financial estimates ... in this product line stuff the real benefits are for large organizations with large portfolios with large investments, and generally, the decision is mostly based on economic evaluations,” (Evaluation #5 - Expert #4).*

Similarly, in Evaluation #3, some participants suggested including economic factors as part of **APPLIES**, *“Perhaps incorporate the study of costs or fixed values to understand the risk of implementing PLE in an organization,” (Evaluation #3 - Open Questions);*

“There are other business discovery tools, such as organizational performance metrics as well as financial indicators that could help people have more information to make a better decision,” (Evaluation #3 - Open Questions);

*“Considering that the economic factor is normally so important for decision-makers, it seems to me that **APPLIES** itself could implement a basic financial analysis,” (Evaluation #3 - Open Questions).*

One solution that was initially considered as a possible alternative was to include a quantitative analysis that would incorporate some of the proposed metrics in the area of product line engineering to calculate the ROI, such as the SIMPLE method (Clements et al. 2005). However, bearing in mind the difficulty that some participants had when answering the statements to do with economics (Statements 62 and 63), using an existing economic model is not necessarily a good alternative. The SIMPLE model requires, for example, information such as the estimated percentage of reuse, the cost of developing reusable statements, the organizational cost of adopting PLE and it is very likely that this information will be unfamiliar for the people using **APPLIES**. In fact, some authors in the literature explained that estimating the inputs required by the economic models on product lines is problematic due to uncertainties, inexperience or lack of reliable data (Ganesan et al. 2006, Krüger et al. 2016, Koziolok et al. 2016).

Moreover, findings from Evaluation #7 indicate that the interviewed industry experts do not use the existing economic models. For example, one of the experts explained that it is difficult to estimate the values required by the economic models, since many of these values are unknown *a priori*:

“Asking people to give us the data is difficult because they don’t know it... They can tell you afterwards, once they’ve collapsed all the duplication, but right today they don’t know because it takes a product line mentality to be able to take measures like that,” (Evaluation #7 - Expert #9).

In addition, as Expert #9 stated: *“There is no need for precision, or even accuracy because on average the PLE triples everyone’s productivity, so the improvements are so evident that no precision is needed in the early stages ... I mean you’re gonna say ‘oh product line engineering is terrible because it wasn’t 300 percent, it was*

only two hundred and eighty percent?’, No. If it’s 350% you’re gonna be mad? No, you’re not,” (Evaluation #7 - Expert #9).

According to Expert #9, one way to illustrate the benefits that help motivate organizations to adopt a PLE approach is to present the results of other organizations that have adopted PLE in the past: “*These cases are public and some of the organizations have very large numbers that show improvements, especially in cost avoidance. Of course these cases are not necessarily related to the organization that’s interested, but when people see the information they say, ‘Oh, I know that organization or I’ve heard about that organization that’s doing this’; so, that helps,*” (Evaluation #7 - Expert #9).

In conclusion, rather than incorporating a detailed quantitative analysis at this point, what seems most useful would be to illustrate the potential benefits and costs of adopting a PLE approach with examples and simple charts. Experts #8 and #9 suggested interesting ways forward in this respect:

“*Try asking “how similar are your products?”, so if they are 80% similar, you’re probably replicating 80% of your work across your product line, and then they say “we didn’t build each one from scratch”, yeah but “you are maintaining them separately” and that’s how you can maybe get a start on this. You can say: how bad is it that you’re doing 80% of your work eight times over or whatever the number the portfolio size is,*” (Evaluation #7 - Expert #9);

“*You can ask how many products do you have, how much commonality is in there, if you compare any two products which is the average amount that is just the same... you count how much duplication there is, you can find simple heuristics like that, they are not perfect metrics but I think they would be interesting,*” (Evaluation #7 - Expert #8).

6.2.3 Functionalities to discard

Two recommendations for additional functionalities were made in the evaluations: (i) to calculate the number of potential products for a product line; and (ii) to extend **APPLIES**’ functionality to evaluate the status of an ongoing adoption. However, these suggestions are rejected for the reasons explained below.

- **Calculate the number of potential products.** According to the CEO from Evaluation #1 it would be useful to incorporate a functionality to calculate potential products because this information also affects the decision. Statement 31 of the *preparation assessment model* (see Table B.3 in Appendix B asks about the number of potential products). **APPLIES** does not have any functionality to calculate this value accurately as it is possible that during the initiation state people may not have enough details to make an accurate estimate. Instead, if an organization decides to adopt a PLE approach, the number of potential products will be calculated more accurately when organizations perform the scoping activity.
- **Extend **APPLIES**’ functionality to evaluate the status of an ongoing adoption.** One academic expert suggested extending **APPLIES** to monitor an organization’s progress in adopting product line engineering: “*I think what is also missing and what would be really interesting would be for the method to accompany the change and to re-evaluate after six months or a year of the migration if it is still worth continuing with PLE or if it should be abandoned.*,” (Evaluation #5 - Expert #4)

APPLIES evaluates the convenience of adopting a PLE approach, but evaluating the status of a product line engineering approach under operation is beyond its scope. Proposals such as the PROBE method (Clements & Northrop 2001a, Northrop et al. 2005), the Family Evaluation Framework (van der Linden et al. 2004, 2007), or the evaluation proposed by Ahmed and Capretz (Ahmed & Capretz 2011a,b, 2010)

are more appropriate to determine the current status of the implementation of a PLE approach and to determine a potential future development approach.

6.3 Summary of Chapter 6: Roadmap

This chapter responds to the last evaluation question *EQ5 - What additions or modifications could improve APPLIES?* In particular, this chapter offers recommendations for a subsequent version of **APPLIES** in terms of its design and functionalities. These recommendations are based on the researcher's analysis and reflection on results presented in the previous chapter and on recommendations gathered from participants in the evaluations.

Regarding the design of **APPLIES**, this chapter presents recommendations for the three levels that constitute **APPLIES**: *conceptualization, operationalization and implementation*.

- **Recommendations for the conceptualization level:** this chapter introduces three lessons learned regarding the *motivation assessment model* as well as three main adjustments to introduce in the *preparation assessment model*.
- **Recommendations for the operationalization level:** in terms of the operationalization level, there were findings regarding the response format, the charts, and the process to conduct the evaluation. Related to the response format, the following strategies could help to avoid subjectivity when people use the response format: include a multiple-choice response format to provide different response options for users, use the same type of response format for all parts of the framework to reduce the learning curve for potential users; and incorporate rubrics.

The charts should be designed using data visualization techniques that provide more effective visual presentations.

Finally, with regard to the evaluation process it could be useful for people conducting the evaluation to share their results with others of different profiles in order to validate the answers entered into **APPLIES**. Another strategy to contrast the results is to produce versions with different statements for different roles. However, in this case **APPLIES** should also include a strategy to consolidate different or even contradictory opinions. Furthermore, the target audience of **APPLIES** should be refined to a more specific segment of people who belong to organizations that have problems managing variability and reuse, where the organization is looking for solutions to address those problems. In addition, a further prerequisite for using **APPLIES** is that organizations should have already defined the domain for which they would expect to use product line engineering.

- **Recommendations for the implementation level:** regarding the tool support that provides the implementation level, an alternative is to continue with Excel because fewer resources are required to develop the tool and users can use it independently. Subsequently, when the content and operation of the framework is mature, a web version could be developed.

In terms of functionalities, this chapter introduces functionalities to add, to modify and to discard:

- **Functionalities to add:** it is necessary to consolidate the results that **APPLIES** delivers in **APPLIES-motivation** and **APPLIES-preparation**. This is important in order to provide the evaluators with an overall result that will assist them in determining the convenience of adopting a product line engineering approach. Four categories of adopters, inspired by the framework for *adoption of electronic data interchange* (Iacovou et al. 1995), could be used as a first alternative to classify organizations according to their maturity level for initiating a PLE adoption: *unprepared adopter*, *potential adopter*, *ready adopter*, and *unmotivated adopter*.

Furthermore, different comments from participants suggested that **APPLIES** could usefully extend the results with recommendations that would assist organizations to prepare themselves to adopt a product line initiative, once the evaluation is complete. Finally, translating the instrument into different languages would help reduce the barriers of language differences and improve understandability of the content.

- **Functionalities to modify:** users should not be able to change the relative importance of the criteria that evaluate preparedness in **APPLIES-preparation** as they currently can do. The reason for this adjustment is that the relative importance of each criterion should represent what the PLE community considers important for successful adoption and, therefore, should not be adjusted by the person carrying out the evaluation. Additionally, rather than asking directly for the economic benefits of adopting a PLE approach, those benefits and costs could be illustrated with examples and simple charts.
- **Functionalities to discard:** two functionalities suggested during the evaluations, but which will not be incorporated in a future release are (i) calculating the number of potential products and (ii) extending the functionality of **APPLIES** to evaluate the status of an ongoing adoption were. In the first case, the initiation stage of the adoption decision process is too early to make an accurate estimate regarding the number of products. Instead, organizations estimate the number of potential products when performing the scoping activity after initiating adoption. In the second case, **APPLIES** evaluates the convenience of adopting a PLE approach, but evaluating the status of a ongoing product lines is beyond its scope. Furthermore, there are already approaches other than **APPLIES** interested in this evaluation such as the Family Evaluation Framework ([van der Linden et al. 2004, 2007](#)), or the evaluation proposed by Ahmed and Capretz ([Ahmed & Capretz 2011a,b, 2010](#)).

As mentioned in Chapter 3 as a result of the empirical evaluations it was expected to obtain different opportunities to improve **APPLIES** because it is itself a new solution. This chapter responds to the last evaluation question introduced in Chapter 3 and thus concludes the presentation of the results of the evaluation phase of this research. These recommendations represent a major contribution of this dissertation, as they serve as inputs for the planning of a next phase of development and evaluation of **APPLIES**.

The next chapter finalizes this dissertation by drawing conclusions from the entire research process. In this chapter, the author summarizes the research, answers the research questions, presents contributions to the academic and industry communities, identifies limitations and lessons learned and finally, outlines areas for future research and further work on **APPLIES**.

Conclusions and future directions

This final chapter summarizes the key points of the research (Section 7.1), responds to the research questions formulated in Chapter 1 (Section 7.2), and summarizes the contributions of this study to the PLE industry and academia (Section 1.5). The chapter goes on to explore lessons learned during the research (Section 7.3), the limitations of the study, and concludes by presenting some perspectives for future research (Section 7.4).

7.1 Conclusions

There are two stages in which the adoption of a new idea occurs in organizations: *initiation* and *implementation*. Between these two stages an adoption decision is made. During the *initiation* stage, people in organizations evaluate the innovative idea and develop an attitude, positive or negative, towards the idea that results in the decision to adopt or reject it. In this sense, deciding to adopt a product line engineering (PLE)¹ approach requires that organizations undergo an *innovation decision process* as they need to decide whether to adopt something that they have never tried before. As part of this process, an organization needs to believe that a change is necessary/desirable, i.e., it is motivated to implement an innovation, and that it has the capacity to implement the change, or in other words, it is prepared to do so.

However, as the literature review demonstrated (see Chapter 2), there is little research into the challenges that are faced, particularly for those who are less proficient in PLE, during the *initiation* stage of an *innovation decision process*. Indeed, newcomers to the field of PLE will encounter a lack of a unified body of knowledge, necessitating a time-consuming search to determine factors that would help with their decision-making process. Even with careful research, their lack of expertise in PLE would make it difficult to objectively evaluate the convenience or otherwise of adopting a PLE approach.

Motivated by the author's own experiences and confirmed by gaps in the literature, (see Chapter 2), the driving question for this dissertation therefore is: *how could newcomers to product line engineering more easily evaluate whether product line engineering is, or is not, convenient for their organization?* This main idea was broken down into two research questions:

- [RQ1] *What factors do newcomers to PLE need to consider in order to evaluate an organization's motivation and preparedness for adopting a PLE approach?*
- [RQ2] *How can these identified factors be organized and operationalized into a framework that assists newcomers to conduct the evaluation?*

¹Product Line Engineering consists of creating a portfolio of related products, by taking advantage of the similarities between them (reusing), while managing their differences (Clements 2015).

In response to these questions, this research follows a Design Science methodology to design, implement and critically evaluate a framework (named **APPLIES**) that enables newcomers to PLE to evaluate to what extent and why product line engineering is, or is not, a convenient innovation for their organization. The framework conceptualizes this convenience by evaluating two constructs: the *motivation* an organization has to adopt a PLE approach and its *preparedness* for adopting such an approach. Such an evaluation framework offers a step forward in reducing subjectivity in decision-making because newcomers can consider factors that do not depend on their knowledge or experience alone. Instead, the information comes from a predefined set of organized factors. In addition, because the framework defines the inputs, outputs and the process for calculating the results, users are able to trace the values that justify the results.

The design of **APPLIES** includes both the content to be evaluated, and the operationalization needed to implement the evaluation in the form of a ready-to-use evaluation instrument, an Excel book. Thus **APPLIES** can be used by potential users with little knowledge of PLE, in order to ascertain whether a PLE approach is convenient for their organization. Once constructed, **APPLIES** was evaluated by respondents of different profiles through eight empirical experiences. Four of the eight experiences included practitioners (Evaluations #1 to #4), and the other four included experts in PLE (Evaluations #5 to #8). Chapter 3 provides further details regarding the methodology followed to conduct the design of **APPLIES** and the empirical experiences.

The critical evaluation of the **APPLIES** framework uses a complementary multi-method design and aims to discover how easy the participants found it to use, how relevant the content is, how useful they found it, and whether they would use it themselves in the future. Additionally, the evaluation collates suggestions for improving **APPLIES**.

In general terms, the evaluation of the **APPLIES** framework returns promising results: respondents believe that **APPLIES** provides useful information and they would recommend it to the target audience: people interested in evaluating the convenience of adopting a PLE approach. **APPLIES** is also found to be useful for identifying an organization's current conditions with regard to adopting product lines: it helps to identify which factors organizations should improve, and provides information on elements to be considered before adopting a PLE approach. Furthermore, all participants of the evaluations that used **APPLIES** (Evaluations #1 to #4) were able to interact with the tool autonomously to evaluate an organization's motivation and preparedness for adopting a PLE approach. Chapter 5 discusses the results regarding the ease of use, content pertinence, perceived usefulness and intention to use **APPLIES**.

Furthermore, the design of the critical evaluation is found to be effective as it returns crucial information on areas where **APPLIES** can be improved. Chapter 6 presents recommendations that can be used to evolve **APPLIES** in the future. These recommendations are the result of the researcher's analysis and reflection on the evaluation results, as well as suggestions collected from the participants of the evaluations.

7.2 Responses to the research questions

This section summarizes and discusses the implications of the key findings to the two research questions: RQ1, which relates to the content of **APPLIES**; and RQ2, which relates to its operationalization.

RQ1. What factors do newcomers need to consider in order to evaluate an organization's motivation and preparedness for adopting a PLE approach?

Motivation

- In order to detect an organization's motivation for adopting a PLE approach, **APPLIES** provides support

to identify whether a product line could be a solution to tackle an organization's threats, take advantage of opportunities, strengthen weaknesses or boost strengths (SWOT analysis). However, the evidence collected from the empirical experiences indicates that **APPLIES** is trying to do too much in this regard. It would be more useful to limit exploration of motivation to identifying only important and urgent problems that might be solved by adopting a PLE approach and that limit an organization's goals. For example, the duplication of tasks and the complexity of managing variability in a product portfolio are two problems that a PLE approach could help to solve and that could motivate adoption.

- It is also important to establish the level of urgency of any identified problem. Indeed, it was found that motivation could change depending on an organization's priorities, so a factor that may be a strong motivation for one organization may be less strong for another.

Preparedness

APPLIES operationalizes preparedness factors into dimensions, criteria and statements. The factors outlined below that need to be considered in order to evaluate an organization's preparedness to adopt a PLE approach come from the initial design of **APPLIES**, combined with the results from its critical evaluation. These factors are grouped into three categories, according to their proposed relative importance. Although the following list is the result of the development and evaluation process described in this dissertation, other evaluation cycles may be necessary to validate the completeness of the factors proposed below.

- *Very Important.* Certain factors that help to identify whether a domain of interest has the conditions needed to develop products using a PLE approach are deemed *very important*. These are: the potential existence of three or more products that would be derived from the product line; the degree of commonality and variability that exists across products; the access that an organization has to people who are experts in the domain of interest and finally the stability expected for the domain of interest. If these domain conditions are not met, a product line engineering approach might not be the right alternative for the organization because these criteria are deemed necessary to elaborate a family of products.
- *Important.* Organizational factors that are considered important and that could affect an organization's preparedness are: the support of top management, the existence of an adoption leader, the support of technical leaders, organizational willingness to change, and willingness of customers to accept the changes that product line engineering could generate. Additionally, staff's openness to change their current practices, to learn new things and to collaborate with one another should be considered.

From a more technical dimension, the evaluation of an organization's preparedness should include: its maturity to follow repeatable processes and staff ability to use configuration management and testing practices.

Finally, from an economic dimension, important preparedness factors include: organizational willingness to invest resources, to free up time for the people who will be part of the adoption project, and to assume the costs related to the adoption and maintenance of a PLE approach. Although it would be highly desirable to make estimates of the economic benefits and costs involved in adopting product line engineering, at this early stage of the innovation decision process it is difficult to achieve because newcomers do not have sufficient know-how to make these estimates. For this reason, early in the decision process, one can ask about the willingness of organizations to invest resources for adoption and, further down the line, illustrate the benefits and costs through examples and charts.

- *Desirable.* Additionally, there are preparedness factors that, while they may facilitate adoption of a PLE approach, are not indispensable, provided the organization is willing to learn and change. These factors

are: prior knowledge and experience in the domain of interest, prior knowledge of product line engineering, current organizational practices that facilitate reuse, and existing artifacts that contribute to the product line.

In conclusion, the preparedness of an organization to adopt product line engineering is a construct composed of multiple factors. Most of these factors transcend the technical aspects of product line engineering, as they are related to organizational factors that reflect an organization's intention to use a new approach. In fact, as mentioned above, it was discovered that in terms of preparedness, it is more important what organizations are willing to do and learn than what they already know and do.

RQ2. How can these identified factors be organized and operationalized into a framework that assists newcomers to PLE to conduct the evaluation?

As mentioned previously, the **APPLIES** framework includes an out-of-the-box Excel tool that enables users to autonomously evaluate the convenience or otherwise of adopting a PLE approach in an organization. The existing design includes response formats used to collect data, performance indicators that summarize the results, and charts used to present the information graphically.

The evaluation indicated that the operationalization of **APPLIES** as it currently stands is functional: newcomers are able to provide information in a relatively short time using the proposed response formats, and no difficulties are indicated with using the tool that operationalizes **APPLIES**. Positive aspects of the existing design include:

- A closed response format is a good choice to capture inputs as participants are familiar with this type of format, and they know how to operate it.
- In addition, this type of format is useful to process results automatically, which facilitates the calculation of scores or the outputs of the evaluation.
- Charts are a valuable way of presenting results and therefore are a feature to keep to summarize the results of the evaluation.

In spite of the overall positive reactions to the evaluation tool, the analysis of results indicates that the following features could improve the operationalization:

- Include a glossary to clarify terms that may be difficult for the people doing the evaluation to understand.
- Include different people (roles) in the evaluation and amend the statements to reflect this change.
- Incorporate a rubric in the response format to guide people in the selection of their responses.
- Include recommendations that guide the interpretation of results.
- Incorporate the assignment of values of importance and urgency to the evaluation of an organization's motivation for adopting a PLE approach.
- Discard the functionality that allows people to customize the relative importance of criteria to evaluate an organization's preparedness.
- Re-design the chart outputs using visualization techniques that enhance the presentation of results in a clear and attractive way.
- Include an extra step to clarify the domain in which a PLE approach would be explored before starting the evaluation.

In conclusion, the design and operationalization of **APPLIES** effectively provides newcomers to PLE with a tool that can be used to autonomously evaluate an organization's motivation and preparedness to adopt a PLE approach. Results of the evaluation provide further insights that can be used to improve the existing tool.

7.3 Lessons learned

The section below presents the author's learning during the process of the entire project. This learning is related to overall insights acquired regarding aspects of the process that worked well, activities that could be done differently in the future, and personal experiences and growth.

7.3.1 Regarding the content of **APPLIES**

At the beginning of the project the author's idea was that **APPLIES** could be used to evaluate the convenience of adopting a product line engineering approach only for software products. However, a lesson learned during the design and evaluation of **APPLIES** is that its scope could be extended to product line engineering in general, since source code is only one artifact of many possible artifacts that a product line could include. A product line might include various types of engineering artifacts required in the creation, implementation, and maintenance of products that belong to the product line (Gregg et al. 2017). These artifacts are, for example, requirements, design documents, source code, models, test cases, procedures, etc. For this reason, in this document the scope and presentation of **APPLIES** refers to Product Line Engineering (PLE) in general and not to software product line engineering in particular.

Other lessons to highlight regarding the content are the following:

- It is necessary to differentiate between factors that, while important for the organization, are not relevant for evaluating the adoption of a product line engineering approach. For example, having a good relationship with customers or having a staff with good technical skills for their jobs are two such factors.
- When designing the statements it is essential to take into account the knowledge and experience of those undertaking the evaluation. For example, people were unable to respond to some factors included in **APPLIES** related to expected economic results related to required investment because they did not have the knowledge or data to do so.

7.3.2 For the next empirical evaluations

7.3.2.1 General lessons

Empirical evaluations are an opportunity to initiate collaborative networks and communicate the research in progress. The empirical evaluations involving experts represented a valuable opportunity to develop contacts with experts and people from organizations, and to realize that the academic community around product line engineering is extremely open to sharing and collaborative. Furthermore, the PLE teaching scenarios at universities provide opportunities to collect empirical evidence that brings product line engineering closer to industrial practice. The typical spirit of knowledge sharing in academic environments could also positively influence the willingness of people to participate in evaluations. For example, the participants in Evaluation #3 showed an exemplary willingness to participate even though this activity was not mandatory or contributed to any grade. In addition, because the Master's in software engineering program is oriented towards practitioners, in Evaluation #3 and #4, a large number of the participants had an active relationship with the software development industry.

Involving different stakeholders is useful to identify wide-ranging problems in the content. One of strengths of this study was the range of roles of the participants involved in the evaluation. The feedback provided by academic experts and industry experts served to identify defects in the content such as interrelated statements, statements to be eliminated, risks of bias, and redaction issues, while the feedback collected from participants who were potential users of **APPLIES** (Evaluation #1 to Evaluation #4) were useful to identify difficulties with statements and with the clarity of wording.

The evaluation with an organization that had no previous experience in PLE (Evaluation #2) and the independent evaluation by the participants of Evaluation #4 were very helpful in identifying the discrimination problem of the adoption drivers included in **APPLIES-motivation**. This difficulty had not been identified in the other evaluations because **APPLIES** had been tested with cases where product line engineering appeared to be a good solution, whereas Evaluation #2 and Evaluation #4 involved cases where adopting a PLE approach would not necessarily be a convenient alternative.

Review the ultimate purpose of the evaluation before selecting an evolutionary or complementary multi-method. In this research, the aim was to include different views on the same evaluation object, in order to collect evidence that would help to decide on changes and improvements. In this case, a *complementary multi-method* would have been appropriate from the beginning. An *evolutionary multi-method* is appropriate if the purpose is to find evidence to confirm or reject the findings of a previous evaluation, such as whether the changes applied to the object of evaluation were relevant, whether the problems were solved, etc. The experience of using a multi-method design in this research coincides with what was reported by Bastos (2011) and Wood et al. (1999) in the sense that the time and effort required to plan, design and organize each evaluation and analyze the data collected is significant, especially with the human component, i.e., the time required to organize subject interviews, transcribe and code the records, analyze the resulting codes, and synthesize the evidence.

7.3.2.2 Data analysis

Field notes are useful to improve the analysis. Field notes were written after each evaluation and were also updated during the analyses. The compiled notes were useful to review the results of the analyses and improve the trustworthiness of the conclusions.

There are free tools available to transcribe audio recordings. To speed up the transcription process, different alternatives were evaluated. For example, Youtube was used in this case, since it provides an automatic transcription of the videos. However, it was found that the resulting transcripts were more accurate for the recordings in English than in Spanish.

Use the right tools for the job. Based on the experience obtained with the multi-method evaluation, as a researcher, I strongly recommend the use of computer-assisted qualitative data analysis software (CAQDAS) to transcribe, code, and analyze the material. These types of tools help to maintain the organization of the research, to stay linked to the original text segment from the raw data, and to record the analysis of the data. For example, when preparing the transcripts, it is necessary to stop, advance and return the audio as the text is produced. Without the right tool, activities such as manually stopping and rewinding recordings are laborious and unnecessarily time wasting for those who produce the transcripts. Specialized tools for these tasks offer features to easily transcribe audios, such as playback speed, rewind interval, and time-stamps to synchronize transcripts with audio or video files. There are paid and free programs for qualitative analysis: some of these are, for example, NVivo, ATLAS.ti, Dedoose and MAXQDA. In particular, in this research MAXQDA was very useful to produce the transcripts and code them for analyzing the results.

Transcribing takes a long time. Although the preparation of transcripts could be left to external research

staff, I decided to do them myself because "*this is an important first step in data analysis[...] it can facilitate the realizations or ideas that arise during analysis*" (Bailey 2008). One limitation to consider, however, is that producing transcripts is a time-consuming task. According to the literature, transcribing one hour of talk at a general level of detail takes at least three hours and can take as much as ten hours with a fine level of detail (Bailey 2008). It took me around 17 hours to transcribe three hours and 20 minutes of recording, approximately six hours per hour of speech.

A lesson learned in Evaluation #2 in this regard is the importance of planning beforehand what information is worthy of being transcribed. For example, in future empirical evaluations, discussions that took place among participants to reach consensus on the responses they provide to **APPLIES** could be omitted. A more efficient option would have been to transcribe only those parts of the audio that were relevant for responding to the evaluation questions, such as the difficulties expressed by the participants in understanding the content of **APPLIES**, the opinions they expressed about the usefulness of the **APPLIES**, or the changes that people suggested to improve it.

Researchers need to decide how they will represent audible data in a written form. Transcribing seems to be a simple technical task. However, it involves decisions about how the audible data will be represented in the text, e.g., unintelligible material, quotations, non-verbal communication, pauses, elements to omit, etc. I would advise researchers to identify what strategy they will use to produce the transcripts and to develop guidelines detailing the rules to be followed in that process. As a guide, I consulted the following sources of information on how to prepare transcripts (Bailey 2008, Minnesota Historical Society Oral History Office 2001, Humble 2016).

7.3.3 Personal experiences to highlight

A personal discovery for me during this project was learning how open the product line engineering community is to the exchange of knowledge and collaboration. Throughout the PhD process, I interacted with multiple researchers interested in product line engineering, and established networks that I hope will materialize in future collaborations. Furthermore, I was blessed with the opportunity of exchanging knowledge with experts, many of whose works I had read. These exchanges were invaluable for my growth, both personally and academically.

Additionally, during this process, I had the opportunity to collaborate on different projects. While outside of the scope proposed for this dissertation, these projects provided invaluable opportunities to apply product line engineering concepts in real environments. In actual fact, these experiences triggered my interest in assisting newcomers to start a product line engineering journey, which is ultimately one of the purposes of the solution presented in this work. Below, I list the papers resulting from these collaboration projects:

- Martin Sierra, María Constanza Pabon, **Luisa Rincon**, Andres Navarro, and Diego Linares. 2019. A Comparative Analysis of Game Engines to Develop Core Assets for a Software Product Line of Mini-Games. In Reuse in the Big Data Era. ICSR 2019. Lecture Notes in Computer Science, Ampatzoglou A., Bhowmik T. (ed.). Springer, Cham, (Vol. 11602, pp. 64–74).
- **Luisa Rincon**, Juan-C. Martínez, María C. Pabón, Javier Mogollón, and Alejandro Caballero. 2018. Creating a Software Product Line of Mini-Games to Support Language Therapy. In Communications in Computer and Information Science (Vol. 885, pp. 418–431)
- Juan-Carlos Martínez, Maria-Constanza Pabón, **Luisa Rincon**, Erika Gutiérrez, Martin Sierra, Gloria Álvarez, Diego Linares, Andres Castillo, Anita Portilla, Valeria Almanza, Juan-C Martinez, Maria-C Pabon, Luisa Rincon, Erika Gutierrez, Martin Sierra, Gloria Alvarez, Diego Linares, Andres Castillo, Anita

Portilla, and Valeria Almanza. 2018. Using Software Product Lines to Support Language Rehabilitation Therapies: An Experience Report. In Proceedings of the 2018 ICAI Workshops (ICAIW) (pp. 1–6).

- **Luisa Rincon**, Edwin Munoz, Juan-C Martinez, Maria-C Pabon, and Gloria Alvarez. 2016. Extractive SPL adoption applied into a small software company. In Proceedings of the XLII Latin American Computing Conference (CLEI)
- **Luisa Rincon**, Gabriel Rodriguez, Juan C. Martinez, Gloria Ines Alvarez, and Maria Constanza Pabon. 2015. Creating virtual stores using software product lines: An application case. In Proceedings of the 10th Computing Colombian Conference (10CCC) (pp. 71–78).

7.4 Limitations of the study

While **APPLIES** represents an important contribution to the field, this section acknowledges the limitations of the design, results and methodology of the study.

7.4.1 Limitations of scope

This research was designed to propose and critically evaluate a solution for assisting newcomers to product line engineering to evaluate whether product line engineering is, or is not, convenient for their organization through the evaluation of two constructs: motivation and preparedness. However, the framework does not offer organizations alternatives other than adopting a PLE approach. Additionally, subsequent activities such as planning for the adoption, implementation or evaluation of an adoption are beyond the scope of this study. In the future, the idea would be to expand the scope to offer support from the early stages of the adoption process to the implementation of this adoption.

7.4.2 Limitations of the results

- **Participant’s nationality.** The perceived usefulness, intention to use, content relevance and understandability of the content were evaluated by collecting the opinions of participants in the empirical evaluations. However, the results might be influenced by cultural perceptions and language. For example although the participants included in the workshop-style evaluations had different profiles (Evaluations #1, #2, #3 and #4), all of them were Colombian and their mother tongue was Spanish. Thus it is possible that the statements (written in English) may have been difficult to understand or interpreted differently. In the future it would be interesting to include people of different nationalities in the evaluations to expand the spectrum of findings.
- **Psychometric properties.** The redundant statements to remove from the assessment models depend on findings from the literature, as well as the results of the empirical evaluations. However, there are other statistical analyses useful to validate the organization of content, such as the Cronbach coefficient. This analysis is useful to identify redundant statements, however it requires about 200 different samples. It is expected that in the future, the evolved version of the content will collect the sample of responses needed to analyze the relevance of the content with techniques that enable the discarding of unnecessary statements from the statistical results.²
- **Collect more evidence regarding the ease of use of the tool that **APPLIES** provides.** The results

²See [Hinkin \(1998\)](#).

of the satisfaction questionnaire completed by participants in Evaluation #4 indicated that the instructions for using the tool provided by **APPLIES** were clear, but this is the only evidence obtained in this regard as participants in Evaluation #1, #2 and #3 were accompanied by the researcher. In the future, therefore, it would be prudent to collect more evidence in this regard.

7.4.3 Limitations of data collection

- **Validity of the satisfaction questionnaires.** The satisfaction questionnaires presented in Tables B.5 (which evaluated *perceived usefulness* and *intention to use*) and B.6 (which evaluated *ease of use*) were evaluated for internal consistency using the Cronbach's alpha test. While both questionnaires received an acceptable value making the conclusions valid, the questionnaire in Table B.5 needs improvements to bring the minimum acceptable value up to a more desirable value.
- **Size of the sample used to evaluate the ease of use, perceived usefulness and intention to use.** Less than 30 samples were collected with the questionnaires that evaluate the perceived usefulness, intention to use and ease of use of **APPLIES**. This small sample size limits the use of inferential statistics to make predictions about the data. In the future, it would be ideal to obtain a sample of more than 30 elements to perform parametric tests to make inferences about perceived usefulness, intention to use, and ease of use of **APPLIES** in order to generalize the results found using statistical techniques.

7.5 Future work

The following section outlines potentially fruitful avenues of research to explore in the future, based on analysis of the current research and personal experiences throughout the process.

7.5.1 On the **APPLIES** framework

- **Elaborate a new version of **APPLIES** and start a new evaluation cycle.** Chapter 6 presents a set of recommendations to consider based on the analysis of the evaluation results and the experience collected by the researcher during the two phases followed to conduct this research. A future work therefore is to put into practice those recommendations to produce a new version that represents an evolved version of **APPLIES** as well as to plan, execute and analyze empirical evaluations to initiate a new cycle of improvement.

7.5.2 Other avenues of research

- **Search engine for industrial experiences.** When organizations are in the initial stage of an innovation decision process, the analysis of examples of real applications and similar experiences serves as a source of information to support their decision, since organizations tend to incorporate innovations already tested by other organizations (Rogers 1983). However, in the early years of PLE, a limitation for newcomers was the scarcity of industrial works that reported successful cases of adoption. Over the years, more industrial experiences have become available in the literature but their practical usefulness is limited. The information is abundant, heterogeneous, distributed among diverse sources of information and has different levels of abstraction, which makes it difficult for newcomers to understand, for example, which industrial cases are similar to their own, what positive and negative results have been obtained, and which recommendations are best suited to the organization's conditions.

In order to capitalize on the knowledge published on industrial experiences to serve as a support and inspiration for those interested in adopting a product line engineering approach, it could be interesting to provide a search engine that gathers, synthesizes and presents the information reported by industrial experiences in an attractive way for the user.

- **Gamification techniques to introduce PLE-related concepts.** Once organizations decide to adopt product line engineering, a fundamental aspect for the success of the process is the communication of the change and the training of the stakeholders involved. In order to make this training attractive, gamification techniques could be explored to introduce aspects that favor learning such as emotion, motivation and associative learning.
- **Analyze economic consequences of adopting a PLE approach.** The economic models proposed so far could be improved to be more user-friendly to newcomers. One possibility could be to limit the amount of input data required by the models, even if this would make the estimate less accurate, as this data may be unknown to the users. For example, when an organization has no previous experience in product line engineering it is difficult to estimate values such as the percentage of reuse or the number of months required to set up a PLE approach. In fact, hard-numbers are not always indispensable for convincing decision-makers to adopt product line engineering. There are three reasons for this statement:
 - It has been reported in the literature that economic models have not been as widely used in practice as might be expected.
 - Experts with extensive experience do not make concrete estimates of benefits or costs, because of the difficulties mentioned previously. These experts have accompanied many companies in successful adoption processes.
 - There are multiple success stories of adoption of product line engineering. While it is not possible to say that in all cases companies successfully initiated adoption without carrying out economic estimates, considering the two conditions above it is possible that the adoption would have occurred even if the decision-makers did not have detailed economic estimates.

7.6 Concluding remarks

This dissertation presents a new evaluation framework, named **APPLIES** that aims to assist newcomers to evaluate the convenience of adopting a PLE approach. The insights collected from the empirical evaluations indicate that **APPLIES**, in its current form, is a promising starting point and could be widely accepted by the community.

Some of the barriers that prevent software companies in my country (Colombia) from exploring PLE are: the scarcity of experts in the local context with experience in the adoption of a PLE approach; language barriers; and the high costs involved in international consulting, considering exchange rate limitations. Personally, I hope that the results of this research will contribute to reducing these entry barriers and will allow me, from my role in academia, to make product line engineering more accessible to organizations that could benefit from this promising production approach.

While **APPLIES** is far from complete, it is my hope that this dissertation defines a clear path to follow in the future. Thus, although this particular project concludes with these final thoughts, the journey will continue.

Appendices

Literature review supports

Table A.1: Papers used as reference to elaborate the *motivation* and *preparation* assessment models for **APPLIES v1**

Reference	Citation
K. Schmid and M. Verlage, “The economic impact of product line adoption and evolution,” <i>IEEE Softw.</i> , vol. 19, no. 4, pp. 50–57, 2002. Available: https://doi.org/10.1109/MS.2002.1020287	(Schmid & Verlage 2002)
H. Koziolok et al., “Assessing software product line potential: an exploratory industrial case study,” <i>Empir. Softw. Eng.</i> , vol. 21, no. 2, pp. 411–448, 2016. Available: https://doi.org/10.1007/s10664-014-9358-0	(Koziolok et al. 2016)
J. G. Wijnstra, “Critical Factors for a Successful Platform-Based Product Family Approach,” in <i>Proceedings of the International Software Product Line Conference</i> , pp. 68–89, 2002. Available: https://doi.org/10.1007/3-540-45652-X_6	(Wijnstra 2002)
C. Ebert and M. Smouts, “Tricks and traps of initiating a product line concept in existing products,” in <i>Proceedings of the 25th International Conference on Software Engineering</i> , vol. 6, pp. 520–525, 2003. Available: https://doi.org/10.1109/ICSE.2003.1201231	(Ebert & Smouts 2003)
M. Staples and D. Hill, “Experiences Adopting Software Product Line Development without a Product Line Architecture,” in <i>Proceedings of the 11th Asia-Pacific Software Engineering Conference</i> , pp. 176–183, 2004. Available: https://doi.org/10.1109/APSEC.2004.50	(Staples & Hill 2004)
H. P. Breivold, S. Larsson, and R. Land, “Migrating Industrial Systems towards Software Product Lines: Experiences and Observations through Case Studies,” 2008 34th <i>Euromicro Conf. Softw. Eng. Adv. Appl.</i> , pp. 232–239, 2008. Available: https://doi.org/10.1109/SEAA.2008.13	(Breivold et al. 2008)
W. A. Hetrick, C. W. Krueger, and J. G. Moore, “Incremental return on incremental investment: Engenio’s Transition to Software Product Line Practice,” in <i>Companion to the 21st ACM SIGPLAN conference on Object-oriented programming systems, languages, and applications, OOPSLA’06</i> , pp. 798–804, 2006. Available: https://doi.org/10.1145/1176617.1176726	(Hetrick et al. 2006)
B. J. Pronk, “Product line introduction in a multi-business line context. An experience report,” <i>Int. Work. Prod. Line Eng. Early Steps Planning, Model. Manag.</i> , 2002.	(Pronk 2002)
H. S. Hamza, J. Martinez, and C. Alonso, “Introducing Product Line Architectures in the ERP Industry: Challenges and Lessons Learned,” in <i>SPLC Workshops</i> , pp. 263–265, 2010.	(Hamza et al. 2010)
D. Faust and C. Verhoef, “Software product line migration and deployment,” <i>Softw. Pract. Exp.</i> , vol. 33, no. 10, pp. 933–955, 2003. Available: https://doi.org/10.1002/spe.530	(Faust & Verhoef 2003)
A. Birk, G. Heller, I. John, K. Schmid, T. von der Massen, and R. Bosch, “Product line engineering: The state of the practice,” <i>IEEE Softw.</i> , vol. 20, no. 6, pp. 52–60, Nov. 2003. Available: https://doi.org/10.1109/MS.2003.1241367	(Birk 2002)
F. Ahmed and L. F. Capretz, “An architecture process maturity model of software product line engineering,” <i>Innov. Syst. Softw. Eng.</i> , vol. 7, no. 3, pp. 191–207, 2011. Available: https://doi.org/10.1007/s11334-011-0159-y	(Ahmed & Capretz 2011b)
F. Ahmed and L. F. Capretz, “An organizational maturity model of software product line engineering,” <i>Softw. Qual. J.</i> , vol. 18, no. 2, pp. 195–225, 2010. Available: https://doi.org/10.1007/s11219-009-9088-5	(Ahmed & Capretz 2010)

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Reference	Citation
F. Ahmed and L. F. Capretz, "A business maturity model of software product line engineering," <i>Inf. Syst. Front.</i> , vol. 13, no. 4, pp. 543–560, 2011. Available: https://doi.org/10.1007/s10796-010-9230-8	(Ahmed & Capretz 2011a)
L. G. Jones and L. M. Northrop, "Product Line Adoption in a CMMI Environment," Carnegie Mellon University, Technical report, Tech. Rep. CMU/SEI-2005-TN-028, 2005.	(Jones & Northrop 2005)
G. Böckle et al., "Adopting and institutionalizing a product line culture," in <i>Proceedings of the 2nd International Software Product Line Conference</i> , vol. 2379, pp. 49–59, 2002. Available: https://doi.org/10.1007/3-540-45652-X_4	(Böckle et al. 2002)
D. Muthig, "An Incremental Transition Strategy is Key to a Successful Introduction of Product Line Engineering," <i>Proc. Softw. Prod. Lines Econ. Archit. Implic.</i> , 2001.	(Muthig 2001)
D. Schütz, "Transition to product line engineering," in <i>Proceedings of the 15th European Conference on Pattern Languages of Programs – EuroPLoP'10</i> , Article 19, 2010. Available: https://doi.org/10.1145/2328909.2328933	(Schütz 2010)
K. Schmid and I. John, "Developing, validating and evolving an approach to product line benefit and risk assessment," in <i>Proceedings of the 28th Euromicro Conference</i> , 2002, pp. 272–283. Available: https://doi.org/10.1109/EURMIC.2002.1046172	(Schmid & John 2002)
C. Fritsch and R. Hahn, "Product Line Potential Analysis," in <i>International Systems and Software Product Line Conference (SPLC)</i> , 2004, pp. 228–237. Available: https://doi.org/10.1007/978-3-540-28630-1_14	(Fritsch & Hahn 2004)
J. F. Bastos, P. A. da Mota Silveira Neto, P. O'Leary, E. S. de Almeida, and S. R. de Lemos Meira, "Software product lines adoption in small organizations," <i>J. Syst. Softw.</i> , vol. 131, pp. 112–128, Sep. 2017. Available: https://doi.org/10.1016/j.jss.2017.05.052	(Bastos et al. 2017)
N. Nazar and T. M. J. Rakotomahefa, "Analysis of a Small Company for Software Product Line Adoption – An Industrial Case Study," <i>Int. J. Comput. Theory Eng.</i> , vol. 8, no. 4, pp. 313–322, 2016. Available: https://doi.org/10.7763/IJCTE.2016.V8.1064	(Nazar & Rakotomahefa 2016)
D. Li and C. K. Chang, "Initiating and Institutionalizing Software Product Line Engineering: From Bottom-Up Approach to Top-Down Practice," in <i>Proceedings of the 33rd Annual IEEE International Computer Software and Applications Conference</i> , vol. 1, pp. 53–60, 2009. Available: https://doi.org/10.1109/COMPSAC.2009.17	(Li & Chang 2009)
H. P. Jepsen, J. G. Dall, and D. Beuche, "Minimally Invasive Migration to Software Product Lines," in <i>Proceedings of the 11th International Software Product Line Conference (SPLC 2007)</i> , pp. 203–211, 2007. Available: https://doi.org/10.1109/SPLINE.2007.30	(Jepsen et al. 2007)
S. Bandinelli and G. Sagardui, "Domain Potential Analysis: Calling the Attention on Business Issues of Product-Lines," in <i>Lecture Notes in Computer Science</i> , vol. 1951, pp. 76–81, 2000. Available: https://doi.org/10.1007/978-3-540-44542-5_9	(Bandinelli & Sagardui 2000)
S. Cohen, "Product Line State of the Practice Report," Technical Report CMU/SEI-2002-TN-017, 2002.	(Cohen 2002)
S. Bühne, G. Chastek, T. Käkölä, P. Knauber, L. M. Northrop, and S. Thiel, "Exploring the Context of Product Line Adoption," in <i>Proceedings of the 5th International Workshop on Software Product-Family Engineering</i> , 2004, pp. 19–31. Available: https://doi.org/10.1007/978-3-540-24667-1_3	(Bühne et al. 2004)
J. F. Bastos et al., "Adopting software product lines: a systematic mapping study," <i>Int. Conf. Eval. Assess. Softw. Eng.</i> , no. 1, pp. 11–20, 2011. Available: https://doi.org/10.1049/ic.2011.0002	(Bastos et al. 2011)
M. Jha and L. O'Brien, "Identifying Issues and Concerns in Software Reuse in Software Product Lines," in <i>Lecture Notes In Computer Science</i> , vol. 5791, 2009, pp. 181–190. Available: https://doi.org/10.1007/978-3-642-04211-9_18	(Jha & O'Brien 2009)
L. G. Jones and L. M. Northrop, "Clearing the Way for Software Product Line Success," <i>IEEE Softw.</i> , vol. 27, no. 3, pp. 22–28, 2010. Available: https://doi.org/10.1109/MS.2010.71	(Jones & Northrop 2010)
M. Kircher, C. Schwanninger, and I. Groher, "Transitioning to a Software Product Family Approach - Challenges and Best Practices," <i>10th Int. Softw. Prod. Line Conf.</i> , pp. 163–171, 2006. Available: https://doi.org/10.1109/SPLINE.2006.1691588	(Kircher et al. 2006)
E. Niemelä, "Strategies of Product Family Architecture Development," in <i>Proceedings of the 9th international conference on Software Product Lines</i> , Boston, USA, pp. 186–197, 2005. Available: https://doi.org/10.1007/11554844_21	(Niemelä 2005)

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B. Tekinerdogan, E. Tüzün, and E. Saykol, “Exploring the Business Case for Transitioning from a Framework-based Approach to a Software Product Line Engineering Approach,” in SPLC Workshops, pp. 251–254, 2010	(Tekinerdogan et al. 2010)
K. Pohl, G. Böckle, and F. van der Linden, Software Product Line Engineering. Springer Berlin Heidelberg, 2005. Available: https://doi.org/10.1007/3-540-28901-1	(Pohl et al. 2005)
C. Catal, “Barriers to the adoption of software product line engineering,” ACM SIGSOFT Softw. Eng. Notes, vol. 34, no. 6, p. 1, 2009. Available: https://doi.org/10.1145/1640162.1640164	(Catal 2009)
L. G. Jones and L. M. Northrop, “Clearing the Way for Software Product Line Success,” IEEE Softw., vol. 27, no. 3, pp. 22–28, 2010. Available: https://doi.org/10.1109/MS.2010.71	(Jones & Northrop 2010)
S. Cohen, “Predicting When Product Line Investment Pays,” 2003.	(Cohen 2003)
N. Matsuda, “Problems and Suggestion for Adopting Product Line Software Engineering from Modification Style Development,” in Proceedings of the 11th Asia-Pacific Software Engineering Conference, pp. 568–571, 2004. Available: https://doi.org/10.1109/APSEC.2004.73	(Matsuda 2004)
P. Kuvaja, J. Similä, and H. Hanhela, “Software Product Line Adoption—Guidelines from a Case Study,” in Lecture Notes in Computer Science, vol. 4980, Springer, pp. 143–157, 2011. Available: https://doi.org/10.1007/978-3-642-22386-0_11	(Kuvaja et al. 2011)
J. Bosch, “On the Development of Software Product Family Components,” in Proceedings of the 3rd International Conference on Software Product Lines, vol. 3154, pp. 169–173, 2004. Available: https://doi.org/10.1007/978-3-540-28630-1_9	(Bosch 2004)
E. Tüzün, B. Tekinerdogan, M. E. Kalender, and S. Bilgen, “Empirical evaluation of a decision support model for adopting software product line engineering,” Inf. Softw. Technol., vol. 60, pp. 77–101, Apr. 2015. Available: https://doi.org/10.1016/j.infsof.2014.12.007	(Tüzün et al. 2015)
Mansell, J. (2006). Experiences and Expectations Regarding the Introduction of Systematic Reuse in Small- and Medium-Sized Companies. In Software Product Lines (pp. 91–124). https://doi.org/10.1007/978-3-540-33253-4_3	(Mansell 2006)

APPENDIX B

Material that support **APPLIES**

B.1 Factors to evaluate preparedness in current literature

Table B.1 and B.2 compare the factors that each proposal includes for evaluating respectively motivation and preparedness.

Rows indicate the set of factors included and columns show the name of each approach analyzed. The intersection between rows and columns contains the name that each proposal assigns to the factor. As can be seen in the tables, the number of factors that each proposal includes, as well as their names, vary among the approaches. For example, Transit-PL (Tüzün et al. 2015) and PLTP (Northrop et al. 2005) both include a factor called *process maturity*, while PulSE-eco (Schmid & John 2002) names the same factor *maturity*, and Tecnalía’s *Reuse-invest* names it *management process*. The approach that includes the greatest number of factors is Transit-PL (Tüzün et al. 2015).

Table B.1: Factors proposed in the literature to evaluate motivation for considering the adoption of a PLE approach. Source: author’s analysis.

Factor	Approach						
	Transit PLE (Tüzün et al. 2015)	Reuse-invest (Mansell 2006)	ABB domain assessment (Koziolk et al. 2013, Domis et al. 2014, Koziolk et al. 2016)	Potential Analysis (Fritsch & Hahn 2004)	PULSE -Eco (Schmid & John 2002)	PLTP (Northrop et al. 2005)	Domain potential analysis (Bandinelli & Sagardui 2000)
Motivation	Business motivation	Usefulness of the reuse initiative	Motivation	Quality problems, Complexity problems, Increased differentiated products	Purpose		

Table B.2: Factors proposed in the literature to evaluate preconditions for considering the adoption of a PLE approach. Source: author’s analysis.

Factor	Approach						
	Transit PLE (Tüzün et al. 2015)	Reuse-invest (Mansell 2006)	ABB domain assessment (Koziolk et al. 2013, Domis et al. 2014, Koziolk et al. 2016)	Potential Analysis (Fritsch & Hahn 2004)	PULSE-Eco (Schmid & John 2002)	PLTP (Northrop et al. 2005)	Domain potential analysis (Bandinelli & Sagardui 2000)
Process maturity	Process maturity	Management process, Development process	Development process readiness		Maturity	Process maturity	Release and change management
Organizational support	Organizational structure flexibility	Organizational structure	Organizational fit		Organizational constraints		
Market potential	Market potential, Connection with customers		Market fit	Market for the products	Internal and external market		
Openness	Attitude for change	Attitude to the improvement					
Management support	Management support	Management commitment					
Domain knowledge	Domain knowledge	Experience in the domain		Business unit develops more than one product; Exclusions: seldom new product, commissioned products			
Potential products	Clearly defined scope						
Risk	Risk tolerance						Risk taker, indifferent, adverse. Organization, Personnel, Process and Products risk
Software engineering capability	Software architecture competence	Development process	Architecture				
Ratio of software	Ratio of software			Software is small; negligible software development effort			
Product line awareness	SPLE knowledge		Knowledge				
Stability	Technological stability Domain stability	Technology		Technological change	Stability		

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Factor	Approach						
	Transit PLE (Tüzün et al. 2015)	Reuse-invest (Mansell 2006)	ABB domain assessment (Koziolk et al. 2013, Domis et al. 2014, Koziolk et al. 2016)	Potential Analysis (Fritsch & Hahn 2004)	PULSE-Eco (Schmid & John 2002)	PLTP (Northrop et al. 2005)	Domain potential analysis (Bandinelli & Sagardui 2000)
Commonality and variability	Commonality and variability of products	Variability and commonality	Reuse potential	Common features, common qualities, same part of software used in more than one product, Custom products	Commonality and variability		
Reuse potential	Reuse potential, degree of control over product specification	Legacy products	Reuse culture	Same software part used in more than one product	Existing assets coupling and cohesion	Legacy context	
ROI	Expected ROI		Business case				Investments, expenses savings
Resources	Funding source stability, Potential overall investment, Potential upfront investment Degree of globalization, tool support	Resource allocation	Business model: Funding		Resource constraints		
Others			Future outlook	Competitive situation			

B.2 Assessment models comparison between **APPLIES v1** and **APPLIES v2**

This section has two tables presenting and comparing the *motivation assessment model* (Table B.3) and the *preparation assessment model* (Table B.4) of **APPLIES v2** and **APPLIES v1**.

APPLIES v2 is an intermediate result from the analysis of evaluations #1 and #5. This version was used in evaluations #2, #3, #4,#6 and #8.

To facilitate traceability between both versions, each table contains and compares the texts and shows a code to identify and keep track for the reason that motivate the change. The following is the meaning of the codes: C1: Modification suggested by experts; C2: Wording improvement; C3: Delete; C4: Delete due to merging with other items; C5: Adjust to incorporate other items; C6: No change; C7: Open issue.

Notice that in statements where the tables do not have text for **APPLIES v1** this means that there were no changes between the text included in **APPLIES v1** and **APPLIES v2**.

Table B.3: Comparison *motivation assessment model* from APPLIES V2 and APPLIES v1

Id	Name	Description	Changecode
Strength-based drivers			
1	Retain customers	The organization retains its current customers due to the variability among their products (Ahmed & Capretz 2011b)	C6
2	Gain customers	The organization gains new customers due to the variability of their products (Ahmed & Capretz 2011b) – APPLIES v1 The organization gains new customers due to the variability among their products (Ahmed & Capretz 2011b) APPLIES v2	C1
3	Legacy code	The enterprise has reusable legacy code that it would like to translate into a more maintainable form (Cohen 2002) APPLIES v1 The enterprise has reusable legacy code that it would like to refactor into a more maintainable form (Cohen 2002) APPLIES v2	C1
Opportunity-based drivers			
4	Customize products in short time	The market requires an increasing number of specialized products in a short time. These products might be developed by the organization (Wijnstra 2002), (Li & Chang 2009), (Jepsen et al. 2007)	C7
5	New market	There is a new niche market with shared characteristics. The company expects to enter to enter to this market (Wijnstra 2002)	C7
6	Similar market	The market is “similar enough” to set features that can be shared across product variants. However, there are still differentiating characteristics (Bühne et al. 2004) APPLIES v1 The market is “similar enough” to set features that can be shared across product variants and at the same time there are still differentiating characteristics (Bühne et al. 2004)	C7
7	Similar customer profile	There are similarities in customer profiles or customer business needs (Ebert & Smouts 2003) APPLIES v1 There are similarities in customer profiles or in customer business needs (Ebert & Smouts 2003) APPLIES v2	C1, C7
8	Similar incoming plans	There are overlapping elements in the plans for different products,. e.g. upcoming trends or domain-specific technologies that are expected to be used within many products in the future (Koziolek et al. 2016)	C7
9	Technology advances	Outdated technology that the product relies on will cause it to be abandoned (Koziolek et al. 2016) APPLIES v1 Technological advances make possible to migrate existing products with heterogeneous technologies to the same technology (Pronk 2002) APPLIES v2	C1, C7
Weakness-based drivers			
10	Repeated maintenance tasks	When the company fixes defects or makes minor enhancements, the same task needs to be repeated for every single client (Staples & Hill 2004), (Breivold et al. 2008), (Hetrick et al. 2006)	C6
11	Repeated bugs	Testers find repeated bugs with similar causes(Li & Chang 2009)	C6

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Id	Name	Description	Change code
12	Duplicated source code	The company has identical or highly similar software code segments due to poor reuse practice such as cut and paste programming practices (Staples & Hill 2004), (Li & Chang 2009), (Breivold et al. 2008), (Hamza et al. 2010) APPLIES v1	C1
		The company has identical or highly similar software code segments due to poor reuse practice such as <u>clone-and-own</u> (Staples & Hill 2004), (Li & Chang 2009), (Breivold et al. 2008), (Hamza et al. 2010) APPLIES v2	
13	Scattered source code	Product variants are implemented in source code files that are scattered in different parts of the code repository (Staples & Hill 2004), (Breivold et al. 2008), (Hetrick et al. 2006)	C7
14	Uncontrolled product parts	The organization has an uncontrolled set of parts that run separately (Faust & Verhoef 2003)	C7
15	Similar products implemented differently	Current products are similar, but were implemented in different ways or without interaction among the teams (Li & Chang 2009), (Hamza et al. 2010), (Birk 2002)	C7
		Current products are similar, but were implemented in completely different ways or without interaction among the teams (Li & Chang 2009), (Hamza et al. 2010), (Birk 2002)	
16	Graphical style differences	Common products have graphical style differences (Li & Chang 2009) APPLIES v1	C2
		Common products have <u>unintended</u> graphical style differences (Li & Chang 2009) APPLIES v2	
17	Modifications affect other products	It is difficult to ensure that modifications of specific products do not affect the quality of other products (Breivold et al. 2008)	C6
18	Products include all functionalities	New products include the complete set of functionalities and services even though they do not require everything to work properly (Breivold et al. 2008)	C7
19	Difficulties to derive new products profitably	Old name: Difficulties to derive new products economically It becomes impossible to derive new products, or update existing ones with the current production infrastructure (Schmid & Verlage 2002), (Staples & Hill 2004) APPLIES v1	C1
		It becomes <u>unprofitable</u> to derive new products, or update existing ones, with the current production infrastructure (Schmid & Verlage 2002), (Staples & Hill 2004) APPLIES v2	
<hr style="border-top: 1px dashed #000;"/>			
Threat-based drivers			
20	Technology advances	Old name: Abandoned products technology Outdated technology that the product relies on will cause it to be abandoned (Koziolek et al. 2016) APPLIES v1	C1
		Outdated technology caused current products will be abandoned (Koziolek et al. 2016) APPLIES v2	

Table B.4: Comparison between the *preparation assessment model* from **APPLIES V2** and the *preparation assessment model* from **APPLIES v1**

Id	Description	Previous text APPLIES v1	Changecode
Operational dimension			
Commitment of key actors (very important)			
1	<u>Managers</u> will support the initiative for exploring a product line solution (Jepsen et al. 2007), (Cohen 2002), (Bühne et al. 2004), (Bastos et al. 2011), (Jha & O'Brien 2009)	Relevant stakeholders will support the initiative for exploring a product line solution (Jepsen et al. 2007), (Cohen 2002), (Bühne et al. 2004), (Bastos et al. 2011), (Jha & O'Brien 2009)	C2
2	The product line project would have a <u>project leader with authority to make decisions and support the idea of change</u> (Schütz 2010), (Li & Chang 2009), (Cohen 2002), (Bastos et al. 2011), (Jones & Northrop 2010)	The product line project will have a “product line champion” or “angel” at a high level of the hierarchy (Schütz 2010), (Li & Chang 2009), (Cohen 2002), (Bastos et al. 2011), (Jones & Northrop 2010)	C2
<hr style="border-top: 1px dashed black;"/>			
Customers connection (important)			
3	The organization uses feedback from customers to develop new products or services (Ahmed & Capretz 2011b), (Ahmed & Capretz 2011a)		C7
4	The organization can attract new customers (Ahmed & Capretz 2011a)		C7
5	The organization can retain existing customers (Ahmed & Capretz 2011a)		C7
6	The organization has brand loyalty (Ahmed & Capretz 2011a)		C7
<hr style="border-top: 1px dashed black;"/>			
Degree of control over product specification (important)			
7	The organization can control how the product is developed, e.g. there are no design constraints such as specific components use or support of customer-specific interfaces (Bühne et al. 2004)		C7
8	The organization can balance customer and product-centered approaches in product development [12], (Kircher et al. 2006)		C7
9	The organization has the potential of offering new products that market has not anticipated (Ahmed & Capretz 2011a), (Bühne et al. 2004)		C7
<hr style="border-top: 1px dashed black;"/>			
Domain knowledge (very important)			
10	Engineers have enough expertise to decide what is common and <u>variable</u> in the area where the <u>product line might be implemented</u> (Nazar & Rakotomahefa 2016), (Cohen 2002)	Engineers have enough expertise to decide what is common in the domain (Nazar & Rakotomahefa 2016), (Cohen 2002)	C5
11	The organization has the know-how to capture the requirements that will cover the product line (Ahmed & Capretz 2011b), (Ahmed & Capretz 2011a)		C6

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Id	Description	Previous text APPLIES v1	Changecode
12	The organization has successful products in the <u>area</u> where they want to adopt a <u>product line approach</u> (Cohen 2002), (Bühne et al. 2004)	The organization has successful products in the targeted market (Cohen 2002), (Bühne et al. 2004)	C2
13	<i>Merged in the item 10</i>	Engineers have enough expertise to decide what is variable in the domain (Nazar & Rakotomahefa 2016), (Cohen 2002)	C4
14	Domain-specific talent exists in the organization (Bühne et al. 2004)		C6
15	<i>Merged in the item 16</i>	Staff have expertise in the potential product line domain (Bühne et al. 2004)	C4
16	Organization has <u>theoretical knowledge and experience in the potential domain</u> (Cohen 2002) (Bühne et al. 2004)	The organization has experience in the product line domain (Cohen 2002)	C5
Market potential (very important)			
17	<u>Organization is among the market leaders</u>	Market share is held by largest companies in which the organization is included (Bühne et al. 2004)(Bühne et al. 2004)	C1
18	<i>Eliminated – It is eliminated because it is not a decisive factor for the adoption of product lines. Instead it is a factor that could be an advantage in any type of project.</i>	The organization is a pioneer in the development of products (Ahmed & Capretz 2011a), (Bühne et al. 2004)	C3
19	<i>Merged in the item 22</i>	Current customer needs are known (Bühne et al. 2004), (Niemelä 2005)	C4
20	<i>Merged in the item 22</i>	Future customer needs could be predicted (Bühne et al. 2004), (Niemelä 2005)	C4
21	<i>Merged in the item 22</i>	The organization could predict the evolution of the products (Wijnstra 2002), (Tekinerdogan et al. 2010), (Pohl et al. 2005)	C4
22	It is <u>foreseeable a future market for the products</u> that will be developed under the scope of the product line (Ahmed & Capretz 2011a), (Koziolek et al. 2016), (Schmid & John 2002), (Fritsch & Hahn 2004), (Wijnstra 2002), (Li & Chang 2009), (Bandinelli & Sagardui 2000), (Bühne et al. 2004), (Niemelä 2005, Tekinerdogan et al. 2010, Pohl et al. 2005)	A future market for the products under the scope of the product line is foreseeable (Ahmed & Capretz 2011a), (Koziolek et al. 2016), (Schmid & John 2002), (Fritsch & Hahn 2004), (Li & Chang 2009), (Bandinelli & Sagardui 2000), (Bühne et al. 2004)	C5
Openness (very important)			
23	Individuals in the organization are open to change how they interact with colleagues and other departments (Ahmed & Capretz 2010), (Muthig 2001) (Birk 2002)	Individuals in the organization are open to change how to interact the different business areas (Ahmed & Capretz 2010), (Muthig 2001), (Birk 2002)	C1
24	If needed, individuals are open to change their <u>current practices</u> (Ahmed & Capretz 2010), (Muthig 2001), (Birk 2002)	If needed, individuals are open to change their development practices (Ahmed & Capretz 2010), (Muthig 2001), (Birk 2002)	C5
25	<i>Merged in the item 24</i>	If needed, individuals are open to change their task assignments (Ahmed & Capretz 2010), (Muthig 2001), (Birk 2002)	C4

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Id	Description	Previous text APPLIES v1	Changecode
Organizational willingness (very important)			
26	<u>If necessary the organization is willing to do internal changes such as modify the organizational structure</u> (Koziolk et al. 2016), (Li & Chang 2009), (Jones & Northrop 2010), (Catal 2009)	The organization might be will to perform internal changes required to adopt a product line approach (Koziolk et al. 2016), (Li & Chang 2009), (Jones & Northrop 2010), (Catal 2009)	C2
27	Different organizational units are able to work collaboratively (Ahmed & Capretz 2010), (Koziolk et al. 2016), (Wijnstra 2002), (Breivold et al. 2008), (Jones & Northrop 2010)		C5
28	<i>Merged in the item 27</i>	The cross-functional activities around departments can be synchronized (Ahmed & Capretz 2010), (Breivold et al. 2008)	C4
29	Individuals <u>would be willing to try new techniques, tools or ways to do things</u> (Cohen 2002)	The individuals would be committed to try product line engineering methods (Cohen 2002)	C1
Potential products (very important)			
30	The organization develops more than one product that <u>shares functionalities</u> and could be integrated into the product line (Fritsch & Hahn 2004)	The organization develops more than one product that could be integrated into a product line (Fritsch & Hahn 2004)	C1
31	There is potential to create at least three different products that <u>share common functionalities</u> (Fritsch & Hahn 2004), (Cohen 2003)	The potential product line could create at least three different products (Fritsch & Hahn 2004), (Cohen 2003)	C1
32	Products of the product line will be developed with a stable technology (refresh rate >5 years) (Fritsch & Hahn 2004), (Wijnstra 2002), (Cohen 2003), (Matsuda 2004)		C7
Process discipline (very important)			
33	Requirements are documented in a structured and disciplined way (Ahmed & Capretz 2011b), (Koziolk et al. 2016), (Ebert & Smouts 2003)		C7
34	<u>The company defined, specified and, optionally, optimized its processes using any systematic approach e.g., CMMI</u> (Jones & Northrop 2005)	The organization has experience applying standardized engineering procedures for developing its products. i.e. CMMI (Jones & Northrop 2005)	C1
35	There is explicit documentation which is up-to-date and available for being reviewed (Ahmed & Capretz 2011b), (Bastos et al. 2017), (Bühne et al. 2004), (Kircher et al. 2006)	There is explicit documentation which is up-to-date and available for reviewing (Ahmed & Capretz 2011b), (Bastos et al. 2017), (Bühne et al. 2004), (Kircher et al. 2006)	C2,C7
36	The organization has formal plans to maintain its assets (Ahmed & Capretz 2011a)		C6
Product line awareness (very important)			
37	The organization staff has knowledge about product line engineering. Otherwise, they are willing to learn (Böckle et al. 2002)		C6

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Id	Description	Previous text APPLIES v1	Changecode
38	If needed, the organization would provide the infrastructure, training, and materials that could require a software product line approach (Cohen 2002), (Bühne et al. 2004), (Jha & O'Brien 2009), (Kuvaja et al. 2011)	If needed, the organization would provide capacity building about product line engineering (Cohen 2002), (Bühne et al. 2004), (Jha & O'Brien 2009), (Kuvaja et al. 2011)	C2
39	Company will allocate employees' time dedicated to product line adoption (Bühne et al. 2004)	The company will allocate employees' time for capacity building about product line engineering (Bühne et al. 2004)	C1
Technical dimension			
Commonality and Variability (very important)			
40	Potential products have common features (Ahmed & Capretz 2011b), (Schütz 2010), (Fritsch & Hahn 2004), (Pronk 2002), (Cohen 2002)		C6
41	Potential products have common nonfunctional requirements (Fritsch & Hahn 2004)	Potential products have common qualities (Fritsch & Hahn 2004)	C1
42	Potential products have differentiating features (Bühne et al. 2004)	Potential products have differentiating characteristics (Bühne et al. 2004)	C1
Reuse aptitude (desirable)			
43	The company has established reuse processes for providing or consuming external assets (Koziolek et al. 2016)	The company has established reuse processes for providing or consuming external components (Koziolek et al. 2016)	C1
44	Current organizational structure allows developing reusable assets (Koziolek et al. 2016)	Current organizational structure allows developing reusable components (Koziolek et al. 2016)	C1
45	Staff members are considering possible future use when they develop software artifacts (Ahmed & Capretz 2010), (Koziolek et al. 2016)	Management and developers considering possible future use when they develop software artifacts (Ahmed & Capretz 2010), (Koziolek et al. 2016)	C2
46	Technical staff is willing to develop new software based on reusable components rather than build it from scratch (Jha & O'Brien 2009)	Technical staff agree developing new software based on reusable components rather than build it from the scratch (Jha & O'Brien 2009)	C1
47	There is low coupling between existing software artifacts (Schmid & John 2002)		C7
48	There is high cohesion between existing software artifacts (Schmid & John 2002)		C7
49	There is an explicit organization vocabulary shared by the staff about terms related to the area where a product line approach is interesting (Koziolek et al. 2016)	There are unified and shared understanding of domain-specific terms among the staff (Koziolek et al. 2016)	C1, C2
Reuse potential (very important)			
50	The legacy code could be incorporated into the product line approach with minor or no changes (Koziolek et al. 2016)		C6
51	Assets which might be incorporated into the product line, are reliable to use (Jha & O'Brien 2009)	Components, which might be incorporated into the product line, are reliable to use. (Jha & O'Brien 2009)	C1

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Id	Description	Previous text APPLIES v1	Changecode
52	Current products are common enough for reusing key design elements (Ebert & Smouts 2003)		C6
53	There are technical or business artifacts that might be reused (Jha & O'Brien 2009), (Jones & Northrop 2010), (Matsuda 2004)	There are technical and business artifacts such as field service technician documentation, customer engineering, or interaction that might be reused (Jha & O'Brien 2009), (Jones & Northrop 2010), (Matsuda 2004)	C2
54	Architectures of different products are modeled and aligned (Koziolok et al. 2016), (Bosch 2004)	Architectures of different products are aligned (Koziolok et al. 2016), (Bosch 2004)	C1, C7
55	The company follows industry standards (Koziolok et al. 2016), (Bandinelli & Sagardui 2000), (Cohen 2002)	The company is pledged to the industry standards (e.g., for protocols, interfaces, components) (Koziolok et al. 2016), (Bandinelli & Sagardui 2000), (Cohen 2002)	C1
56	There is technology compatibility among products to incorporate into the product line (Koziolok et al. 2016)		C6
Software engineering capability (very important)			
57	The organization has a strategy to control the change management in their artifacts (Ahmed & Capretz 2010), (Ahmed & Capretz 2011a), (Jones & Northrop 2005), (Koziolok et al. 2016), (Jones & Northrop 2010), (Matsuda 2004)		C6
58	<i>Removed: It is eliminated because it is an abstract concept that is evaluated concretely with the other items that belong to the same assessment criterion</i>	The organization has a strong software engineering capability (Jepsen et al. 2007), (Bühne et al. 2004), (Jones & Northrop 2010)	C3
59	There are established developer roles, such as software architects, testers, developers (Koziolok et al. 2016)	There are established developer roles, such as software architects and reuse coordinators (Koziolok et al. 2016)	C2
60	Staff have technical competence in the technology that might be used for implementing the product line (Böckle et al. 2002), (Bühne et al. 2004)		C7
61	<u>Proprietary tools used to develop the current products are not a barrier to adopt a product line approach</u> (Bühne et al. 2004)	The organization is independent on proprietary tools built and used to support a single system approach (Bühne et al. 2004)	C1, C7
Economic dimension			
Economic indicators (desirable)			
62	The potential return on investment (ROI) of the software product line meet the organizational financial target (Ahmed & Capretz 2011a), (Bandinelli & Sagardui 2000), (Cohen 2002), (Matsuda 2004)		C7
63	The maintenance cost of the former products without planned reuse is higher than migrating the products towards a product line approach (Ahmed & Capretz 2011a)		C7
Readiness to invest (important)			
64	There is a budget for investments (Schütz 2010), (Cohen 2002), (Catal 2009)		C6

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Id	Description	Previous text APPLIES v1	Changecode
65	The organization is willing to do regular investments to keep code healthy and keep the number of variations manageable (Jha & O'Brien 2009)		C6

Readiness to pay migration costs (desirable)			
66	The enterprise is willing to pay costs for training people in SPL engineering (Jha & O'Brien 2009)	The enterprise is willing to pay the costs for training people in SPL engineering (Jha & O'Brien 2009)	C2
67	The enterprise is willing to pay costs for building the reusable assets that will support the product line initiative (Koziolek et al. 2016)	The enterprise is willing to pay costs for building the core asset base (Koziolek et al. 2016)	C1

B.3 Material that support the empirical evaluations

B.3.1 Close-ended satisfaction questionnaires

Notice that in both Tables B.5 and B.6 the labels presented to guide the minimum and maximum value of the response options (known as anchors) change to align the response options with the question wording. For example, the label for the minimum value in the item PU-1 is “Strongly disagree”, but the label for the minimum value in the item EaseOfUse-3 is “Difficult to understand”.

Table B.5: Items to evaluate the perceived usefulness and intention to use **APPLIES**

Id	Factor	Subfactor	Item	Min anchor	Max anchor	Sample size				Total
						Eval. #1	Eval. #2	Eval. #3	Eval. #4	
PU-1	Perceived usefulness	Assess motivation	Using APPLIES I can assess the extent to which a company is motivated to adopt a product line	Strongly disagree	Strongly agree	1	1	14	9	25
PU-2		Assess	Using APPLIES I can assess the extent to which a company is prepared to adopt a product line	Strongly disagree	Strongly agree	1	1	14	9	25
PU-3		Justify the decision	APPLIES provides me with useful information to convince decision-makers to adopt a product line approach	Strongly disagree	Strongly agree	1	1	14	9	25
PU-4		Overall satisfaction	Overall, how satisfied are you with the information provided by APPLIES to assess companies' motivation and preparation to adopt PLE?	Very dissatisfied	Very satisfied	1	1	14	9	25

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Id	Factor	Subfactor	Item	Min anchor	Max anchor	Sample size				Total
						Eval. #1	Eval. #2	Eval. #3	Eval. #4	
IU-1	Intention to use	RecommendationI	I would recommend APPLIES	Strongly disagree	Strongly agree	1	1	14	9	25
IU-2		Likely to use	I would use APPLIES	Strongly disagree	Strongly agree	1	1	14	9	25

Table B.6: Items to evaluate the **easy to use** of **APPLIES**. Source of data (*Evaluation ##*)4

Id	Subfactor	Component	Item	Min anchor	Max anchor	Sample size
EaseOfUse-1	Understandability	Motivation assessment model	The statements included in APPLIES-motivation were	Difficult to read	Easy to read	9
EaseOfUse-2		Preparation assessment model	The statements included in APPLIES-preparation were	Difficult to read	Easy to read	9
EaseOfUse-3		Charts	The charts delivered by APPLIES were	Difficult to understand	Easy to understand	9
EaseOfUse-4		Report	The content of the final report was	Difficult to understand	Easy to understand	9
EaseOfUse-5	Easy to use	Directions	Directions for using APPLIES were	Not at all clear	Totally clear	9
EaseOfUse-6		Response format	The response-format proposed by APPLIES was	Difficult to complete	Easy to complete	9

B.3.2 Frequency tables (Responses)

Table B.7: Frequency table: responses received related to the **perceived usefulness** of **APPLIES** (n=25)

Id	Item						Min	Max					
		1	2	3	4	5							
		Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%		
PU-1	Evaluate company's motivation	0	0%	0	0%	5	20%	16	64%	4	16%	3	5
PU-2	Evaluate company's preparation	0	0%	0	0%	5	20%	12	48%	8	32%	3	5
PU-3	Justify the decision	0	0%	0	0%	6	24%	12	48%	7	28%	3	5
PU-4	Overall satisfaction	0	0%	0	0%	3	12%	15	60%	7	28%	3	5

Table B.8: Frequency table: responses related to the **intention to use APPLIES** (n=25)

Id	Item	1		2		3		4		5		Min	Max
		Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%		
IU-1	Use APPLIES	0	0%	0	0%	3	12%	13	52%	9	36%	3	5
IU-2	Recommend APPLIES	0	0%	0	0%	1	4%	14	56%	10	40%	3	5

Table B.9: Frequency table: responses related to the **ease of use of APPLIES** (n=9)

Id	Item	1		2		3		4		5		Min	Max
		Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%		
EaseOfUse-1	The statements included in APPLIES-motivation were <i>difficult to read (1) - easy to read (5)</i>	0	0%	1	11%	2	22%	4	44%	2	22%	2	5
EaseOfUse-2	The statements included in APPLIES-preparation were <i>difficult to read (1) - easy to read (5)</i>	0	0%	1	11%	2	22%	4	44%	2	22%	2	5
EaseOfUse-3	The charts delivered by APPLIES were <i>difficult to understand (1) - easy to understand (5)</i>	0	0%	0	0%	4	44%	3	33%	2	22%	3	5
EaseOfUse-4	The content of the final report was <i>difficult to understand (1) - easy to understand (5)</i>	0	0%	1	11%	3	33%	1	11%	4	44%	2	5
EaseOfUse-5	The response-format proposed by APPLIES was <i>difficult to complete (1) - easy to complete (5)</i>	0	0%	1	11%	0	0%	1	11%	7	78%	2	5
EaseOfUse-6	Directions for using APPLIES were <i>not at all clear (1) - totally clear (5)</i>	0	0%	1	11%	0	0%	6	67%	2	22%	2	5

B.3.3 Cronbach's alpha when items are removed

Table B.10: Cronbach's alpha when items from Table B.5 are removed

Item	Cronbach's alpha (if removed)
PU-1	0.694
PU-2	0.736
PU-3	0.654
PU-4	0.738
IU-1	0.602
IU-2	0.735

B.3.4 Charts interpretation

B.3.4.1 Sources of data

Table B.11: Distribution - sources to evaluate the interpretation of the charts provided by **APPLIES**

Evaluation	Chart # 1	Chart # 2	Chart # 3
	Alignment with adoption drivers	Share of selected drivers	Preparation grid
Evaluation #1	1	1	1
Evaluation #3	1	1	–
Evaluation #4	19	19	19
Evaluation #5	2	2	2
Total	23	23	22

B.3.4.2 Results

Table B.12: Frequency table: results obtained when people interpreted the charts provided by **APPLIES**

	Chart # 1			Char # 2			Chart # 3		
	Alignment with adoption drivers n=22			Share of selected drivers n=22			Preparation grid n=21		
	Correct	Not used	Incorrect	Correct	Not used	Incorrect	Correct	Not used	Incorrect
Aggregated results %	35%	57%	9%	52%	35%	13%	82%	18%	0%
Aggregated results #	8	13	2	12	8	3	18	4	0

B.3.5 Qualitative data - instrument data collection

B.3.5.1 Questions stated in the qualitative analysis

Table B.13: Questions that guide interviews / focus groups

Item	Question
Content [Evaluation #1, #2, #5 and #8]	What other elements do you think we could include in APPLIES to support the decision in favor or against a product line approach?.
	Is there any criterion missing? Which one?
	Do you think there is any cases in which an organization is definitively not adequate for adopting a product line approach? (Only in evaluation#5)
Content pertinence and importance [Evaluation #7]	In your experience, is the motivation for adopting a product line engineering approach more often driven by problems that companies need to solve or is it driven by goals that companies want to achieve? Why?
	In which of both cases have you found a company's disposition better to support the PLE adoption?
	Do you think there are criteria that make a company better prepared for adopting a product line approach? Which of those criteria are important and which of them are desirable?
	Let's suppose that an organization is well prepared for adopting PLE, in which cases do you consider this company should reject the adoption?
	In your experience, how decisive is the economic factor when a company is evaluating to adopt or reject a PLE solution? Why?
Perceived usefulness [Evaluation #1, #2, #4 and #5]	How useful do you think is APPLIES ? Why?
	How helpful do you think could be APPLIES for helping organizations to make an informed go/no go decision? Why?
Intention to use [Evaluation #1, #3, #4 and #5]	Why or why not would you use APPLIES ?
	Why or why not would you recommend APPLIES ?
	Do you find any reasons why an organization interested in exploring a product line approach would not use APPLIES ? which ones ?
Ease of use [Evaluation #1] Recommendations [Evaluation #1, #2, #3, #4 and #5]	How helpful for interpreting the results was the color progression of the preparation grid?
	Which improvements do you think APPLIES requires for getting better in its purpose?
	Do you have any other recommendation to improve APPLIES ?
	If you have any other comment, suggestion or opinion you can write it down in this space

B.3.5.2 Qualitative data - comments

Table B.14: Comments regarding the operationalization defined for APPLIES

Topic	Comments
Binary response format	<p>“In our case there are some questions where the answer is certainly yes or no, but there are also other cases where ‘yes’ or ‘no’ is insufficient to respond,” (Evaluation #2 - CEO)</p> <p>“What happens here is that either you say yes, or you say no and that’s not necessarily the case,” (Evaluation #2 - Leader in innovation)</p> <p>“It seems to me that there is a high contrast between the two evaluation methodologies... I think it is better to have only one,” (Evaluation #2 - Leader of Knowledge Management)</p> <p>“the binary format may lead the respondent to think that he must select “yes” on everything,” (Evaluation #(#2 - CEO)).</p>
Five-points response format	<p>“I like the nominal scale because sometimes the numbers can be suggestive, so the scale as it is makes one think not about what number to put but about how much one agrees with the statements... I found the scale easy to fill in and I like it that way and not with numbers...,” (Evaluation #1 - CEO).</p> <p>“I think five answer choices are good. Although the difference between strongly agree and agree is narrow with this scale the position is clear when you agree and when you disagree,” (Evaluation #2 - Leader of Innovation).</p> <p>“It seems to me that the evaluation in APPLIES is more qualitative than quantitative, so I think the scale is fine. I don’t think it is necessary to go into the detail of putting metrics to each statement. Instead, leaving the statements a little more open allows people to discuss them among themselves before selecting an answer,” (Evaluation #5 - Expert #1).</p> <p>“There are questions that if I revisit them again I might have doubts about what I answered, or that I might answer differently in a future opportunity...this could be resolved if a frame of reference is provided, because with a frame of reference we would have the guide to arrive at the same conclusions. For example, in our case, version management was not done in Git but in folders. It would be good to know in that case whether it would be better to select ‘agree’ or ‘totally agree’ in the response options,” (Evaluation #1)</p> <p>“The results would be much more accurate if it is clearer what the extreme values of the scale mean and what the intermediate values of agree and disagree mean,” (Evaluation #2).</p> <p>“It is necessary to include in the response format an option that includes an option ‘Does not apply’ with a value of zero or a percentage of zero,” (Evaluation #1 - CEO).</p>
Self-evaluation	<p>“If you let organizations go off on their own and self-assess, most of the time they never come back because they don’t understand it... people are confused ... we guide them with face to face guidance and we run workshops ...If we’re there and they start to misunderstand something, we can take them and bring them back to the middle of the road,” (Evaluation #8 - Expert # 8).</p> <p>“Your goal of course is to make the self-assessment as accurate as possible,” (Evaluation #8 - Expert # 9).</p>
Incorporate more options in the response format	<p>“Instead of ‘yes’ or ‘not’ the answer could be “yes, but it’s not the most important thing” (Evaluation #2 - leader in knowledge management),”</p>
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Topic	Comments
	<p>“A response format that goes from strongly agree to strongly disagree is better because it offers more freedom, you don’t feel so compelled in your responses and you feel less influenced to make a radical decision...The answer could be ‘yes but not every time’, ‘yes but it depends on’,”(Evaluation #2 - leader in innovation)</p> <p>“One option would be that instead of ‘yes’ or ‘no’ the answer would be a percentage of affinity: how much affinity do you have with x question? Where for example 1 is not enough. In this way, the person who answers would have more freedom,”(Evaluation #2 - leader in architecture)</p>

Table B.15: Comments related to the ease of use of the outputs included in **APPLIES**

Chart	Topic	Comments	
Perceived usefulness	Positive comments	<p>“the outputs of APPLIES help me to identify criteria that organization members would be willing to change, and to detect those things where there might be some resistance,”(Evaluation #1 - CEO)</p> <p>“the way APPLIES presents the results can easily be translated into business terms,”(Evaluation #3 - Open Questions)</p> <p>“I would use APPLIES for the summary report that it provides,”(Evaluation #3 - Open Questions)</p> <p>“APPLIES offers good outputs because they are a map of the state of the organization. The charts that APPLIES delivers are useful for consultants who can go into organizations and analyze whether or not it is worth adopting PLE because you can discuss with them their strengths and problems,”(Evaluation #5 - Expert #1)</p> <p>“These analysis charts are very nice,”(Evaluation #5 - expert #3)</p> <p>“I like your pie chart and things like that, it’s a richer way to show data than just an integer,”(Evaluation #8 - Expert #8)</p>	
		Negative comments	<p>“People immersed in the topic of product lines may see and interpret the results but people who do not have this knowledge should do so carefully because the outputs are not very clear,”(Evaluation #3 - focus group)</p>
		All adoption drivers are not equally important	<p>“not all the criteria have the same weight for organizations,”(Evaluation #3 - Focus Group).</p> <p>“I believe that the number of adoption drivers helps to define a strategy for the implementation of the product line, but not to decide whether to proceed with the adoption or not. For example, if the number of adoption drivers is below two, I don’t think the answer is not to adopt a PLE approach but to implement it in phases,”(Evaluation #3 - Focus Group).</p>
			There is no appropriate minimum or maximum number of adoption drivers to recommend adopting product line engineering

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Chart	Topic	Comments
		<p>“an organization might select more than 60% or 70% and I don’t know if that’s a rate that allows you to make a decision to say yes or no. It is more about the motivation of the person who is using APPLIES, but I am not sure that there is a minimum number of adoption drivers that should be selected,” (Evaluation #5 - Expert #5).</p>
Share of selected drivers [APPLIES-motivation]	Positive comments	<p>“it can be interesting to know if the organization could adopt PLE because it is a great opportunity for them or because they really can no longer maintain the variants or the development of the products, etc.,” (Evaluation #5 - Expert #1).</p>
	Unbalanced quantity of adoption drivers.	<p>“there are categories of adoption drivers that have more elements than others. This difference can bias the chart; for example, there are more weaknesses than threats,” (Evaluation #5 - Expert #1)</p> <p>“the proportion of adoption drivers is biased by the number of questions in each category. For example, this chart will not show 50% in the category of threats because the total number of threats does not exceed 20% of the total questions,” (Evaluation #5 - Expert #5).</p>
	Difficulties understanding the content	<p>“I find this chart difficult to understand, it could be more suggestive,” (Evaluation #1 - CEO)</p> <p>“looking at the chart, I would not know whether or not the organization would be motivated to adopt a PLE approach,” (Evaluation #3 - Focus Group);</p> <p>“I think this chart ‘share of selected drivers’ is not clear,” (Evaluation #3 - Interview).</p> <p>“The percentages did not look good, they overlapped each other and when trying to move them the whole chart moved,” (Evaluation #1)</p>
Preparation grid [APPLIES-preparation]	(-) Difficulties understanding the content	<p>“I think it would make more sense to have all the green-colored quadrants on the same side,” (Evaluation #5 - Expert #1)</p> <p>“I would have a scale for the four quadrants between zero and five. Then you can have weaknesses that are intensity five and strengths that are intensity five, instead of saying that the weakness is the low number on the same scale,” (Evaluation #5 - Expert # 4)</p> <p>“The scores are hidden in a text box with size font 8,” (Evaluation #3 - Open questions)</p> <p>“Some numbers in the preparation grid overlap each other,” (Evaluation #3 - Open Questions).</p>
	It takes a long time to interpret the chart	<p>“I found this chart hard to understand. Only after seeing another colleague’s result I understood that the factors move from the bottom to the top depending on their score. So the same element can move from being a threat to an opportunity and the same goes for weaknesses and strengths,” (Evaluation #4 - Open Questions).</p> <p>“now that I understand the chart it’s not that bad but it’s complicated to understand,” (Evaluation #5 - Expert # 1).</p> <p>“Either you give up this distinction internal-external, or you need to come up with more external, otherwise it’s useless. Try to come up with more external criteria but if you don’t find any forget this distinction,” (Evaluation #5 - Expert #4).</p>

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Chart	Topic	Comments
	This chart is useful	<p>“With the colours green, yellow and red it is easy to detect when something is good, something needs attention and something is bad,” (Evaluation #1 - CEO)</p> <p>“The background colors provide information. I understand that what’s green is fine while what’s red is a risk... This chart guides users with the colors and positions,” (Evaluation #5 - Expert # 3)</p> <p>“If you tell me that green means okay, red it’s a point of concern and yellow it’s in between, it’s fine it’s intuitive,” (Evaluation #5 - expert # 4)</p>
	Useful information	<p>“I think APPLIES is a very good tool, not only because of the calculation of the scores in each evaluation criterion but also because of the last chart (referring to the preparation grid). This chart summarizes the information very nicely. This chart shows how prepared the organization is to take the risk,” (Evaluation #1 - CEO)</p> <p>“I liked that a summary appears at the end. I want to see in black and white if the product lines would be adequate and the numbers on the chart are clear to me,” (Evaluation #2 - CEO)</p> <p>“It seems to me that this chart provides useful information to identify how prepared the organization is,” (Evaluation #5 - expert #1)</p> <p>“This chart gives information on what strengths and weaknesses the organization has to adopt PLE ... This chart gives a very nice overview,” (Evaluation #5 - expert #3)</p>

Table B.16: Comments related to the ease of use - Tool support

Topic	Comments
Positive comments	<p>“It’s easy to operate,” (Evaluation #3 - Open questions)</p> <p>“APPLIES is easy to use, concise and provides clear results,” (Evaluation #4 - Open questions)</p> <p>“I wouldn’t use it for the usability it provides,” (Evaluation #3 - Open question);</p>
Elements to improve	<p>“It would change the application. I suffered filling in every question, it’s not clear how it should be used,” (Evaluation #3 - Open questions)</p> <p>“It is not clear how to use the tool to the point that you need a 10-minute training to use it... it should not require any training,” (Evaluation #3 - Open questions)</p> <p>“Although the tool is easy to fill in, I would like to see the Excel workbook cleaner, i.e. showing less information.,” (Evaluation #2 - Leader of Architecture)</p>

Table B.17: Comments regarding the content included in **APPLIES-motivation**

Comments
<p><i>“I think you need to identify different dimensions. Here they are all mixed up ...it looks like the set is taken from a larger set of possibilities and we don't see a clear structure or systematic analysis in this list. That's why it's important to think of dimensions before thinking of lists of stuff. Ideally when it's well structured and controlled the list emerges from the dimensions, you cross the dimensions and then you know the possibilities,” (Evaluation #5 - Expert #4).</i></p>
<p><i>“This type of solution rapidly helps organizations to get an idea of whether the product lines could be useful to the organization. However, I am left with the doubt of when does one say no? Because the questions lead you almost always to say yes. ¹ That is, answering ‘no’ would not be possible ... Our business is a custom software development organization, so everything that has to do with software development fits, and everything that has to do with new technologies in software development also fits our case,”(Evaluation #2 - CEO).</i></p>
<p><i>“I don't even have an organization and when I read the adoption drivers that APPLIES currently has I would answer yes because you are asking almost only about the benefits... There are many other ways to solve the problems you are showing in the adoption drivers, and it is not necessarily software product lines that have to be the solution. For example, almost everything proposed in software engineering is focused on correcting the weaknesses described by the adoption drivers. What you have here could be motivating, but in reality there are more ways than product lines to solve them,”(Evaluation #5 - Expert #5).</i></p>
<p><i>“I understand that there are many reasons why the adoption of the product line could be useful...those drivers could depend on the type of company, or the type of product line that you want to create or the type of products that the company develops,” (Evaluation #1 - CEO)</i></p>
<p><i>“Nothing is really controlled here, each project goes its own way, so literally the response to the question is “yes”. However, I answered “no” because in our case, everything works separately and this is not a problem for us, each client has a different product with its own source and this is not a problem, this is how the business works,” (Evaluation #2 - CEO).</i></p>
<p><i>“you would need a rating more related to how important the adoption drivers are to the organization,” (Evaluation #2 - Leader of Architecture).</i></p>
<p><i>“not all the criteria have the same weight for the organizations. There could be, for example, weaknesses that have a high impact and strengths that even if selected do not bring much benefit to the organization,”(Evaluation #3 - Group Discussion).</i></p>
<p><i>“With respect to the adoption driver ‘Current products are similar, but were implemented in completely different ways or without interaction between the teams’, my team consisted of only one person, so this adoption driver would not apply to me,” (Evaluation #1 - CEO).</i></p>
<p><i>“You can almost ask two questions: “how important is it, and how urgent is it? If I don't do it what will happen, what terrible thing will happen? those questions might help managers because they have so many things to worry about, that they might be over optimistic. So, if somebody really points out that there's a problem, it's important, and it's urgent and we're not doing anything about it, there's motivation,” (Evaluation #8 - Expert #9).</i></p>

¹This idea was supported by the innovation manager and the leader of architecture.

Table B.18: Comments regarding the content included in **APPLIES-preparation**

Quotes	Evaluation							
	1	2	3	4	5	8		
“It seems to me that APPLIES addresses the right topics like reuse, variability, commonality, etc...,” (Evaluation #1 - CEO)								•
“It seems to me complete regarding the key points of weaknesses, threats, strengths and opportunities that the organization has,” (Evaluation #3 - Open Questions)								•
“ APPLIES covers not only the organization’s technical capabilities but also the organizational aspects and interests that the organization might have from a business perspective. This coverage generates strong confidence in the evaluation,” (Evaluation #4 - Open Questions)								•
“ APPLIES takes into account the different factors that are affected when implementing a product line,” (Evaluation #3 - Open Questions)								•
“On the part of APPLIES-preparation it seems to me that the criteria are very well developed... I like it,” (Evaluation #5)								•
“It seems to me that the items cover what a company should evaluate before starting a product line engineering approach. The comments for improvement are small and specific,” (Evaluation #5- Expert #5)								•
“I think the questions are well focused on operational, economic and technical aspects,” (Evaluation #1 - CEO)								•
“ APPLIES assesses three important aspects (operational, technical and economic) when deciding whether to adopt a PLE,” (Evaluation #3 - open questions)								•
“ APPLIES covers all the factors that must be taken into account when adopting product line engineering,” (Evaluation #4 - open questions)								•

Table B.19: Comments regarding the statements and the assessment criteria included in **APPLIES-preparation**

Comments
“Organizations want to get new customers and keep the ones they get, but those criteria are more of an organization’s concern than a sign of preparation to adopt product lines,” (Evaluation #5 - Expert # 5)
“It’s a general characteristic of the organization, but whether it has a variability management issue or not.... Coca-Cola is able to attract new customers and it does not have a relation with PLE,” (Evaluation #5 - Expert # 4)
“if the organization develops general-purpose software, the most likely is that there are larger organizations in the market, and for customized software, a market share is not defined ,” (Evaluation #5 - Expert #5).
“Having the potential of offering products that the market has not anticipated is a benefit of adopting a PLE approach not a sign of preparedness for doing it,” (Evaluation #4 - Expert #4)
“I don’t consider that the use of proprietary technologies, such as Visual studio and .Net are an impediment to adopting a PLE approach,” (Evaluation #5 - Expert #2)

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Comments
<p>“Not sure about the consequences of that,” (Evaluation #5 - Expert #1).</p> <p>“if people do not know details about what the product lines are, they will not know in which technology the product line will be implemented because there can be many things. For example, variability can be implemented in many different ways. The question should rather be oriented to identify if the people in the organization are willing to learn new technologies that allow the implementation of a product line,” (Evaluation #5 - Expert #5 -)</p>

Table B.20: Comments collected regarding content understandability

Topic	Quotes	Evaluation					
		1	2	3	4	5	8
General comments	“I think the questions are fine but there are some that need more context and others that can be separated into parts ... there are some questions that are ambiguous concerning what the people who answer them may think,” (Evaluation #1 - CEO)	•					
	“There were some questions that were not entirely understandable... In the weaknesses is where perhaps there were more ambiguities in our case,” (Evaluation #2 - CEO)	•					
	“There are some questions that could be explained in more informal terms to make them simpler,” (Evaluation #3 - open questions)			•			
	“ APPLIES offers an abstraction of the essential factors to consider in order to implement or reject a PLE,” (Evaluation #3- open questions)			•			
Some terms need explanations	“ I felt a bit lost answering the questions about motivation, as they leave room for doubts and can be misinterpreted,” (Evaluation #4 - open questions)				•		
	“It seems to me that the term variability is complex. While I was diligently looking at the instrument when I saw the term I thought about it in terms of what we reviewed at the beginning: that with configurations I would have the product that the customer wants right there. But then if I have good variability does that mean I make the product with almost zero additional code for it and then I don't need to maintain it?,” (Evaluation #2 -leader of knowledge management)	•					
	“The user didn't remember what potential products were so I had to explain the concept,” (Evaluation #4 - comments from the instrument)					•	
	“What's the market?, we understand what a product is pretty intuitively, but if we call it a market then the products in it are necessarily related otherwise it's two different markets, so if you say there is similarity products in the market yes always! So you need to define market other than a set of related products, maybe there are other factors that make it a market or not.... So try to to come up with a definition of what's the market, what's the product and what's the product line,” (Evaluation #5, expert #5)(Evaluation #5 - expert #4)						•
	“When you say domain-specific you mean variant-specific?,” (Evaluation #5 - expert #4)						•

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Topic	Quotes	Evaluation					
		1	2	3	4	5	8
	<p>“The word ‘domain-specific’ is not clear, you have to explain whether domain means a business related concept or domain means a technology related concept,” (Evaluation #5 - expert #5)</p> <p>“What do you call a product-centric approach rather than a customer-centric approach?” (Evaluation #5 - expert #4)</p> <p>“I felt a bit lost answering the questions about motivation as they leave room for doubts and can be misinterpreted,” (Evaluation #4 - Open Questions)</p> <p>“The term components can be interpreted in many ways. How about calling it artifacts?” (Evaluation #5 - expert #5)</p>					•	
Some terms could be simplified	<p>“I don’t understand what ‘legacy code’ ‘product line champion’, ‘brand loyalty’ means,” (Evaluation #1 - CEO)</p> <p>“There were terms that you would suppose a person working in the software domain would understand, but my client didn’t understand or didn’t have very clear concepts, such as: ‘legacy code’, ‘product focused approach’, ‘artifacts’, ‘assets’,” (Evaluation #4 - open questions)</p> <p>“You must specify what are ‘assets’ since I had to give examples to the user... the user thought it was just code, so you have to define what it is,” (Evaluation #4 - open questions)</p> <p>“Do the people who are filling out APPLIES know what ‘product line engineering methods’ mean?” (Evaluation #5 - expert #5)</p> <p>“Would potential APPLIES users understand what ‘core asset base’ is? If not, I recommend to change the term because people who are not into the field might do not understand this term,” (Evaluation #5 - expert #5)</p>	•				•	
	<p>“There are words that due to my level of English I don’t fully understand...given that APPLIES is in English is more difficult to understand for those of us who do not fully master the language,” (Evaluation #1 - CEO)</p> <p>“Another aspect to take into account to improve APPLIES is the language,” (Evaluation #3 - open questions)</p> <p>“I would recommend a version in Spanish,” (Evaluation #4 - open questions)</p> <p>“I think it would be great to have the same tool in Spanish,” (Evaluation #4 - open questions)</p>	•				•	
	<p>“I consider that some questions are repetitive, several times I returned to check if I had not already answered them,” (Evaluation #4 - Open Questions)</p> <p>“It seems to me that there are certain criteria that are repeated,” (Evaluation #5 - expert #5)</p> <p>“The categories are good but many are very interrelated,” (Evaluation #5 - Expert #4)</p>					•	
	<p>“I consider that some questions are repetitive, several times I returned to check if I had not already answered them,” (Evaluation #4 - Open Questions)</p>					•	
The English content limits the understanding of non-English speaking users	<p>“There are words that due to my level of English I don’t fully understand...given that APPLIES is in English is more difficult to understand for those of us who do not fully master the language,” (Evaluation #1 - CEO)</p> <p>“Another aspect to take into account to improve APPLIES is the language,” (Evaluation #3 - open questions)</p> <p>“I would recommend a version in Spanish,” (Evaluation #4 - open questions)</p> <p>“I think it would be great to have the same tool in Spanish,” (Evaluation #4 - open questions)</p>	•				•	
The assessment models had duplicated content	<p>“I consider that some questions are repetitive, several times I returned to check if I had not already answered them,” (Evaluation #4 - Open Questions)</p> <p>“It seems to me that there are certain criteria that are repeated,” (Evaluation #5 - expert #5)</p> <p>“The categories are good but many are very interrelated,” (Evaluation #5 - Expert #4)</p>					•	
Understandability of the motivation assessment model	<p>“I consider that some questions are repetitive, several times I returned to check if I had not already answered them,” (Evaluation #4 - Open Questions)</p>					•	

Table B.21: Comments regarding the content coverage

Quotes	Evaluation					
	1	2	3	4	5	8
1- Good pertinence						
“ APPLIES evaluates several factors and is exhaustive in each of them,” (Evaluation #3 - open questions)			•			
“ APPLIES covers important aspects for companies,” (Evaluation #4 - open questions)				•		
“In BigLever’s case we went through this exercise of understanding motivation, opportunity, thinking about gaps. I think what you included in APPLIES has good coverage,” (Evaluation #8 - expert #6)						•
2 - Missing factors						
“I would not use it when there are other factors to consider that APPLIES does not consider,” (Evaluation #3 - open questions)			•			
“It could be supplemented with case-specific criteria for which the evaluation is intended,” (Evaluation #3 - open questions)			•			
“I think that questions are not enough or that there are missing questions that can play an important role,” (Evaluation #3 - open questions)			•			
“ APPLIES may have factors that were not taken into account and that could be important for companies,” (Evaluation #4 - open questions)				•		
“I suggest making adjustments and including key technical questions to identify how is the development process that the company uses,” (Evaluation #4 - open questions)				•		

Table B.22: Comments indicating that the point of view of different stakeholders should be considered

Topic	Quotes	Evaluation					
		1	2	3	4	5	8
APPLIES needs inputs from people with different profiles	“It is important to take into account that depending on the stakeholder that is using APPLIES there are factors that may be less relevant or even not applicable. For example, if someone from the technical area is using APPLIES it is possible that they are not interested in the economical evaluation... If we look at the management level some opportunities and weaknesses can be seen from one perspective, but if we look at the technical level opportunities or weaknesses can be seen from a different perspective... I have a technical background, so in general I understand the concepts included in APPLIES , but I am not sure the language is clear enough for other types of stakeholders,” (Evaluation #1 - CEO)	•					
	“Some questions can only be answered by someone who is in the area of development,” (Evaluation #3 - open questions)				•		
	“Questions included in APPLIES are management-oriented. For example, the developers do not necessarily have details about how the company deals with customers,” (Evaluation #3 - open questions)				•		

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Topic	Quotes	Evaluation					
		1	2	3	4	5	8
	“Some items may be considered for only a few types of roles in companies,” (Evaluation #4 - written report)						•
	“What is the profile of the people who have to meet to answer APPLIES ’ questions? I think that people with different profiles should meet in a kind of workshop to answer the questions included in APPLIES because, for example, people with a technical profile ignore operational or economic information and vice versa,” (Evaluation #5 - expert # 1)						•

Table B.23: Contradictory comments: **APPLIES** provides enough data to make a decision

Topic	Comments	Evaluation					
		1	2	3	4	5	8
APPLIES does not provide enough data to make a decision	“The information I received from APPLIES does not give me enough confidence to conclude that a company is motivated or prepared for adopting a product line engineering approach,”(Evaluation #4-open questions)						•
	“I would be convinced that a company would be motivated to use APPLIES , but I am not convinced that from the results of APPLIES companies would be motivated to use product lines,”(Evaluation #5 - expert # 3)						•
APPLIES provides enough data to make a decision	“After using APPLIES I feel more confident to decide for or against adopting product line engineering in my company because it allows me to see where my company is located to apply this approach,”(Evaluation #1- CEO)						•
	“I consider that the most difficult part of implementing of product line engineering approach is to make the viability decision... APPLIES would help me to make my decision to start the implementation of the product lines,”(Evaluation #3 - open questions)						•
	“It is an useful tool to be able to identify, at an early stage, situations in which an approach such as product line engineering is not adequate,”(Evaluation #3 - open questions)						•
	“It is difficult to assess whether it is feasible or advisable to use PLE in a company, and APPLIES makes it easier to make this decision,”(Evaluation #3 - open questions)						•
	“ APPLIES offers a well-founded view on whether or not to implement PLE,”(Evaluation #3 - open questions)						•
APPLIES serves as a starting point for further analysis before a decision is made	“The information I get from APPLIES is not enough to make the decision, I would say I want to know more things, but the good thing is that APPLIES gives you insights about where you need to analyze in more detail. For example, in our case we have to confirm if the percentage of reuse is as high as we expect,”(Evaluation #2 -leader of innovation)						•
	“The degree of control we have over product specification is something that APPLIES advises us to review in detail,”(Evaluation #2 -leader of knowledge management)						•

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Topic	Comments	Evaluation					
		1	2	3	4	5	8
	<p>“I would use it as a first base measure, but not as a determining tool to start a product line in a business, I consider that the information allows me to know the business more deeply, but it does not give me 100% certainty,” (Evaluation #3 - open questions)</p>			•			
	<p>“I would recommend it for a quick study of the possibilities of integrating PLE in a company, it generates notions but not determinant information,” (Evaluation #3 - open questions)</p>			•			
	<p>“I would use it as an initial approach to start investigating the possibility of implementing a product line ... it gives a baseline of feasibility analysis,” (Evaluation #3 - open questions)</p>			•			
	<p>“I think it’s a good tool. It serves as a starting point for making a further analysis of whether or not to implement PLE in a company,” (Evaluation #4 - open questions)</p>					•	
	<p>“Since there are no economic model values that indicate how much a product line is going to cost and when we are going to recover the investment and all that, the results of APPLIES are good because they are a map of the state of the company and the graphs that APPLIES delivers are useful for a consultant to go to the company and tell them if it is worth it or not. The consultant can discuss with them what their strengths are or what the problems are. However, APPLIES does not give information that indicates whether or not it is worth adopting product line engineering,” (Evaluation #5 - expert #1)</p>						•

Table B.24: Comments received related to the perceived usefulness of **APPLIES**

Quotes	Evaluation					
	1	2	3	4	5	8
1- APPLIES helps identify companies’ conditions for adopting PLE						
<p>“APPLIES shows the reality of how we were at that time. For instance, the criterion with the worst score was the process discipline, and it was the criterion where there were many things to improve, in fact, we had to change this part completely,” (Evaluation #1 - CEO)</p>						•
<p>“It seems to me that the map and the questions place us in the weak points that need to be attacked and in the strength that we would have. It gives us a panorama that seems clear to me of the current situation to initiate a product line engineering approach,” (Evaluation #2 - leader of knowledge management)</p>				•		
<p>“It provides useful information about the current state of the company,” (Evaluation #3 - open questions)</p>						•
<p>“I feel confident because the questions that are asked lead to a very good questioning about the current state of a company,” (Evaluation #4 - open questions)</p>						•
<p>“I have worked in the company where I carried out the evaluation for 7 years, which helps me to say that the results of APPLIES are very much in line with the reality of the company,” (Evaluation #4 - written document)</p>						•

This table continues on next page.

Quotes	Evaluation					
	1	2	3	4	5	8
2- APPLIES is useful to detect what factors should be improved for adopting PLE						
<i>“It helps me because there are issues that you perceive need to be improved but you do not know what they are. With this tool it is possible to identify those issues, and it becomes something more objective and measurable.... on the technical dimension, it shows where you need to improve or where you are weak,”</i> (Evaluation #1 - CEO)						•
<i>“Filling out these items gives us insight into what things you need to be aware of when adopting a product line engineering approach,”</i> (Evaluation #2 - leader of innovation)						•
<i>“APPLIES is a good guide for transforming the organization because it gives me the basis for identifying what things I should start focusing on to bring the company to the point where it is ready to adopt the PLE approach,”</i> (Evaluation #3 - focus group)						•
<i>“APPLIES is a useful tool to provide the company with a common sense of information that is already perceived within the organization,..., it offers tangible and quantifiable information of different analysis perspectives,”</i> (Evaluation #3 - open questions)						•
<i>“It shows where the mistakes are and how they could be tackled,”</i> (Evaluation #4 - open questions)						•
<i>“I managed to obtain the weaknesses that the company has, and from this I had a basis to define what was right for the company,”</i> (Evaluation #4 - open questions)						•
<i>“It gives a good idea of what factors are positive and negative for implementing PLE. An analysis can be made from these results,”</i> (Evaluation #4 - open questions)						•
<i>“APPLIES seems very useful to me because it tells companies what they need to improve in order to be prepared to adopt product line engineering, which is basically solving weaknesses and threats if any,”</i> (Evaluation #5 - expert # 3)						•
3- APPLIES provides insights on what to consider before adopting PLE						
<i>“It gives me an outline of what questions to ask or in which direction to conduct the interview,”</i> (Evaluation #3 - open questions)						•
<i>“Implementing PLE involves many things and the APPLIES allows to limit the questions that one should ask,”</i> (Evaluation #3 - open questions)						•
<i>“APPLIES offers an abstraction of the essential factors to consider in order to implement or reject a PLE,”</i> (Evaluation #3 - open questions)						•
<i>“APPLIES helps to take into account different factors involved when adopting PLE,”</i> (Evaluation #3 - open questions)						•

Table B.25: Comments received regarding why people would use or recommend **APPLIES**

Topic	Quotes	Evaluation					
		1	2	3	4	5	8
Positive comments	<p>“I would recommend and would have used APPLIES if it had existed when the company took the decision;... this type of tool allows us to give a name to the problems that the company might be facing;... in general I do not see any reason for not recommending it ;... I consider APPLIES is something good that can be recommended,”(Evaluation #1 - CEO)</p>						•
	<p>“It’s a very good basis for making the assessment, I would recommend it,”(Evaluation #3 - open questions)</p>						•
	<p>“I would recommend it to companies that want to evaluate whether it is worthwhile to implement product lines backed by a tool,”(Evaluation #3 - open questions)</p>						•
	<p>“ I would strongly recommend it to those companies that develop software products that have similarities, so that they can evaluate whether they can use of this paradigm of product lines,”(Evaluation #3 - open questions)</p>						•
	<p>“ It is particularly useful for people who have heard about the product lines and are unsure whether they can use it or not. Usually managers are not always so immersed in the technical parts, so I think it’s a good way to turn it into a non-technical language, because at the end of the day the managers are decision-makers, and much of what is important about the product lines is that there are business rather than technical changes. ,”(Evaluation #3 - focus group)</p>						•
	<p>“APPLIES is a useful support tool that evaluates important aspects,”(Evaluation #4 - open questions)</p>						•
	<p>“I would use it for the aspects it evaluates,”(Evaluation #4 - open questions)</p>						•
	<p>“I like the idea of having a tool that helps to visualize why a PLE approach is necessary in the company or why it is not necessary,”(Evaluation #4 - open questions)</p>						•
	<p>“A tool like this leads to the development of a disciplinary basis. It is an organized and rigorous base,”(Evaluation #5 - expert #3)</p>						•
I would recommend it, but I do not know any other	<p>“I would recommend it, as I have not seen another tool capable of giving a prior analysis of the feasibility of adopting PLE,”(Evaluation #3 - open questions)</p>						•
	<p>“It’s a solid basis for decision making, and it’s the only one I know,”(Evaluation #3 - open questions)</p>						•
	<p>“I would recommend it, as I have not seen another tool capable of giving a prior analysis of the feasibility of adopting product line engineering,”(Evaluation #3- open questions)</p>						•

Experts

Li & Smidts (2003) argue that several criteria are necessary when choosing an expert reviewer. In particular, all experts selected in this research satisfied the following conditions:

- Have proved experience by publications or have participated in product-line related projects.
- Have experience in consulting or managing the adoption of product lines in real settings such as enterprises or research projects.
- Have diverse backgrounds and affiliations to achieve a wider perspective and independence in the feedback
- Were willing to participate in the evaluation.

Ten of the eleven experts held a Ph.D. in computer science, all of them have at least ten years of professional experience and a minimum of three years in the product line engineering field and have participated in product-line related projects. Experts # 8, #9 and #10 belong to tool-builder organizations with a widespread commercial use. Those tools were created for developing product-line management technologies, especially for modeling and configuring variability.

The following table presents further details about the whole set of experts involved in the empirical evaluations.

Table C.1: Summary of the experts that participated in the empirical evaluations conducted to evaluate **APPLIES**

Id	Ph.D	Years of experience	Profile	Experience
Expert #1 Jabier Martinez	Yes	More than 10 years	Academic expert	Researcher at TECNALIA Research & Innovation. It has experience in several pilot projects adopting PLE in real systems. These projects were focused in specific subsystems to show the feasibility of PLE at large scale in their systems.
Expert #2 Jaime Chavarriaga	Yes	More than 5 years	Academic expert	Lecturer since 2013 of the <i>Software Factories and Product Lines</i> course at Universidad de los Andes - Colombia. Currently he is the development director of a software development organization.
Expert #3 Juan Carlos Martinez	No	Four and more than 25 years of professional experience	Academic expert	Leader of a research project oriented to create SATRELO a a product line of video-games to support the speech therapy for children with hearing impairment.

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Id	Ph.D	Years of experience	Profile	Experience
Expert #4 Jacques Robin	Yes	Three and more than 30 years of professional experience	Academic expert	He participated as researcher and team leader in REVaMP, an European project to conceive, develop and evaluate a comprehensive automation tool-chain and associated executable process to support round-trip engineering of Software Intensive Systems Product Lines.
Expert #5 Carlos Parra	Yes	More than 10 years	Academic expert	He has scientific publications on topics related to Product Line Engineering, and has also participated in several applied research and consulting projects in public and private sectors.
Expert #6 David Benavides	Yes	More than 15 years	Academic expert	Associate Professor in the Universidad of Seville (Spain) since 2010. He is one of the most recognized researcher on software product lines, software configuration and automated analysis of software variability. He is the chair of the Steering Committee of the Software Product Line Conference and is part of the program Committees of many others of the most important conferences on software variability in the world.
Expert #7 Klaus Schmid	Yes	More than 20 years	Academic expert	Professor of Software Engineering at University of Hildesheim. He has worked in software engineering since the mid 90's, initially mostly in requirements engineering and product line engineering. He has an extensive experience on the organizational and business implications of software engineering in practice. Furthermore, he had participated in several European projects related to the Product Line Engineering field.
Expert #8 Charles Krueger	Yes	More than 20 years	Industrial expert	Founder and CEO of BigLever Software. He has extensive expertise in leading commercial product line solutions in several industries and is knowledgeable about PLE adoption assessment. He has also played a major role in building <i>GEARS</i> , the company's main tool created to support the automatic generation of products for product line systems.
Expert #9 Paul Clements	Yes	More than 20 years	Industrial expert	Pioneer in the PLE field and recognized as co-creator of the book <i>Software Product Lines: Practices and Patterns</i> . He has extensive theoretical and practical experience in supporting commercial organizations to successfully adopt product line engineering and wide knowledge of PLE adoption assessment. Currently, he is the vice president of customer success in BigLever Software, Inc.
Expert #10 Danilo Beuche	Yes	More than 20 years	Industrial expert	Founder of <i>pure-systems GmbH</i> , a software company that offers services and tools for the application of product line technologies in embedded software systems. He has played major roles in the design and development of <i>pure::variants</i> , the main tool that <i>pure-systems GmbH</i> offers to support the feature-based software development. In addition, he has extensive experience as a consultant in the area of product line development.
Expert #11 Jan Bosch	Yes	More than 20 years	Industrial expert & Researcher	Professor of Software Engineering at the University of Groningen and at Chalmers University of Technology. Currently, he is the director of the <i>Software Center</i> organization and in his professional career he has consulted for many companies on product-line projects.

APPENDIX D

Data analysis procedure

Figure D.1 presents the process defined to analyze the collected data. This process was inspired by the guidelines proposed by Saldaña (2013), LeCompte (2003) and was supported by MAXQDA¹, a Computer-Assisted Qualitative Data Analysis Software that assists researchers for transcribing, coding, and later analyzing qualitative data. When the data source is not an audio file but a text, the process starts directly in the third step.

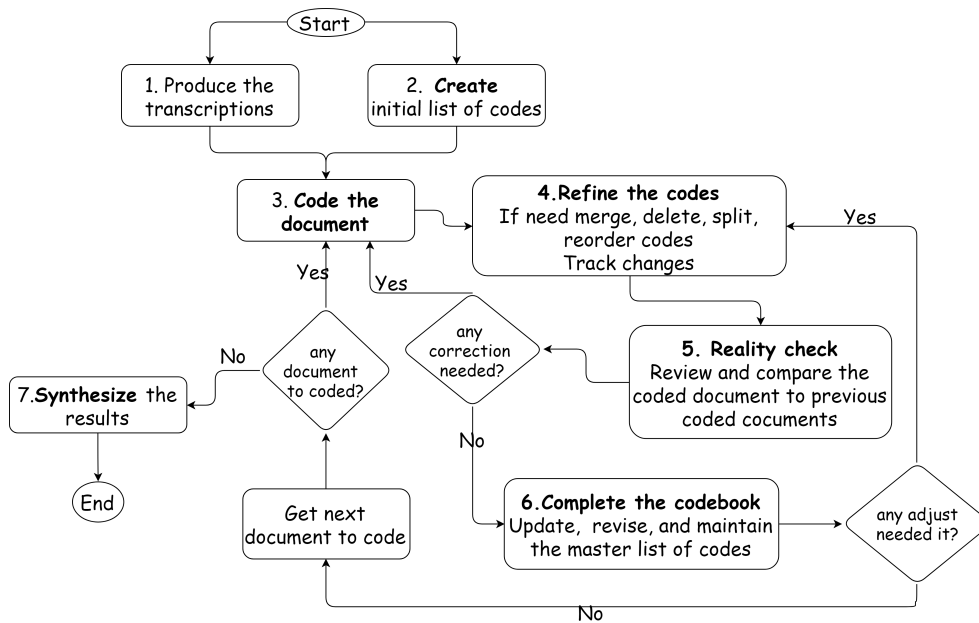


Figure D.1: Data analysis and coding process

Step 1. Produce the transcriptions: Transcribing means converting an audio or video file to a written format (Bailey 2008). Audio recordings were transcribed into a written form because it was easier to study them in detail in this format.

Audio files were transcribed following an “intelligent transcription” strategy *i.e.*, a transcription that intends to improve legibility of the text by *e.g.*, by solving grammatical errors, removing irrelevant words or sentences and adding personal pronouns or articles omitted in the rushed speech. Intelligent transcriptions are useful for academic purposes where legibility and clarity are fundamental (Bailey 2008).

Step 2. Create the initial list of codes: a code is a “tag or label for assigning units of meaning to the

¹<https://www.maxqda.com/>

descriptive or inferential information compiled during a study” (Saldaña 2013). The coding process started with a list of four codes defined arbitrarily: “Framework suggestions”, “New adoption drivers”, “New assessment criteria”, “Evaluation result”. This list was updated as the coding of the transcripts progressed.

The coding process allows researchers to think from raw data up to conceptualization and connection between ideas and concepts. For this reason, coding is an iterative process by nature (Saldaña 2013) where the initial list of codes was updated iteratively. For example, Figure D.2 presents a fragment of the initial and final list (§see Fig.D.2a and §Fig.D.2b respectively). As can be seen in the figure, four codes were added between the initial version and the final version.

Step 3 and 4. Code the document and refine the codes: Codes were assigned to fragments of raw data such as phrases, sentences, or paragraphs. Also, as the coding progressed, more abstract codes were created, i.e., subcategories and categories, to organize concepts thematically. Figure D.2c shows an example of an encoded transcript. The text on the left side of the margin is a code assigned to a transcript extract.

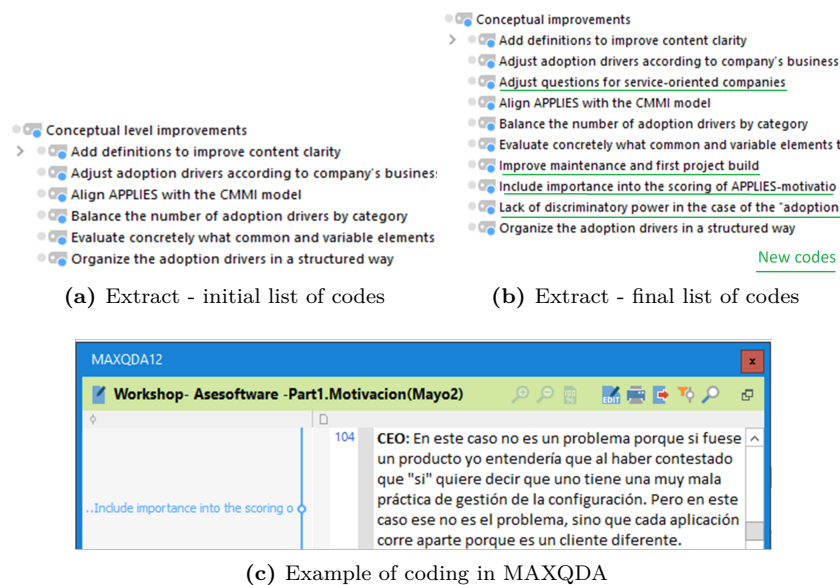


Figure D.2: Coding examples. Screen-shots from MAXQDA

Step 5. Reality check: Each time a transcript was completely coded, it was read again to verify the consistency between the fragments and the assigned codes. Additionally, when code modifications affected fragments that had already been coded, these were rechecked to ensure that the assigned codes were still consistent with the text. In this process, the MAXQDA tool was handy because it offers functionalities to merge, eliminate, divide, or reorganize the code hierarchy.

Step 6. Complete the codebook: The codebook is a document that helps those who codify the material to maintain consistency in the coding process (Saldaña 2013). This document contains the list of codes used during the coding process and the explanation of the meaning of each code and is built iteratively along with the coding process whereby its information is completed and refined as the material is reviewed (Saldaña 2013). There is a codebook that contains codes that arise from the analysis of the material collected in the different empirical evaluations.

Step 7. Synthesize the results: In this step the coded transcripts were analyzed to summarize the results.

The “summary grid” functionality² provided by MAXQDA was used in this step. This functionality facilitates to visualize in one place segments tagged with each code and offers the possibility to sum up abstractly what the transcripts say.

²More info available at <https://www.maxqda.com/help-max18/summary-grid/creating-and-editing-summaries>

APPENDIX E

Towards an evolved version of APPLIES

Table E.1 presents a proposal for the *motivation assessment model* that takes into account the lessons learned about this assessment model. This new proposal does not aim to exhaustively explore a list of problems. Rather, this adjusted assessment model seeks to help people in organizations to identify problems with two issues directly related to a PLE solution: duplicating efforts and managing variability inefficiently. Thus, the adjusted *motivation assessment model* includes three parts: problems, consequences and urgency.

- **Problems.** This part serves to identify problems due to two different causes: duplication of effort and inefficient management of variability. In order to serve as a guide, the assessment model includes examples of problems arising from each of the causes and also provides references to industrial cases that report problems related to each cause. In this version of the assessment model, those conducting the assessment are expected to write down in their own words the organization’s problems, based on the examples provided.
- **Consequences.** This part helps those conducting the evaluation to identify the negative consequences that the organization will face if it does not solve the problems identified. The analysis of consequences is proposed from both the technical and business sides as both could affect business operation. Identifying these negative consequences helps to identify reasons for the adoption because if the adoption goes ahead, its objective should be to avoid these negative consequences
- **Urgency.** This part helps to identify the importance and urgency of the problems and consequences, based on the phases of the change process identified in the TTM model.

Table E.1: Motivation assessment model - evolved version

Question	Case	Notes/clarifications
[Part A] - What significant problems do you believe the organization has in the domain of interest due to one of the following two causes?	1 - A duplicated effort that limits productivity	<i>Example:</i> when someone makes enhancements, some people have to replicate the same task multiple times (once for each related product); there are redundant implementations for the same functionality; there are independent efforts to create or maintain the same functionality in independent products.
	2 - An attempt to manage variability which limits productivity	<i>Example:</i> it is difficult to identify which customer-specific feature is already implemented in which version and for which customer; it is challenging to offer or maintain customized products for each customer; it is difficult to reuse the functionality of one product in another similar product; it is difficult to understand the dependencies between product functionalities, which might cause bugs.

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Question	Case	Notes/clarifications
[Part B] -What negative consequences will occur from a technical and business side if everything continues as it has been up to now?:	Technical side	<i>Example:</i> there is not enough time for adding value; too much time is spent on overheads, or too much time is spent on solving defects.
	Business side	<i>Example:</i> inability to attend the market demand on time; inability to explore new market segments; inability to stay competitive in the current market segment.
[Part C] - Urgency - to what extent are you concerned about the current situation?		5 - <i>Very Concerned:</i> If we don't act now, the organization will not be sustainable. For example, it will become unprofitable to create new products or maintain existing ones.
		4 - <i>Concerned:</i> If we don't act now, the organization will lose an attractive competitive advantage such as the capacity to accept new customers, the organization's participation in the market, the capacity to innovate.
		3 - <i>Partially concerned:</i> If we don't act now, the organization will lose business opportunities, for example, it would not be able to enter new market segments, but it will still remain profitable.
		2 - <i>Mostly unconcerned:</i> If we don't act now, the consequences will not affect the organization in a time frame that worries me.
		1- <i>Not concerned:</i> I did not find any problems, or their consequences do not concern me.

Table E.2: Preparation assessment model - topics to cover in the evolved version of **APPLIES**

Relative importance	Assessment criterion	Factor	Statement ID # (see Table B.4)
Veryimportant	Domain	Access to domain experts	NEW
		Predictability of potential products	NEW
		Technological stability	32
		Number of products	30, 31
		Degree of commonality and variability	40, 41, 42
Important	Commitment of key actors	Top manager support	1
		Existence of an adoption leader	2
		Support of technical leaders	NEW
		Organizational willingness to change	26
		Customer willingness to accept products derived from a PLE	NEW
Important	Staff Openness	Staff openness to change their current practices	23,24, 46
		Staff willingness to learn	29

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Relative importance	Assessment criterion	Factor	Statement Id's (see Table B.4)
		Staff willingness to collaborate	27
Important	Process discipline	Organizations' maturity to follow a repeatable process	34
		Use of configuration management practices	57
		Use of testing practices	NEW
		Organizational willingness to assign people to the adoption initiative	39
Important	Readiness to invest	Organizational willingness to pay maintenance costs	36, 65
		Organizational willingness to pay the cost of adopting a PLE approach	38, 66, 67
		Resources availability	64
		Organization's knowledge of the domain under evaluation	10, 11, 12, 14, 16
Desirable	Domain knowledge	Organization's knowledge of the domain under evaluation	10, 11, 12, 14, 16
Desirable	Product line awareness	Organization's experience with product line engineering concepts	37
Desirable	Reuse aptitude	Current organizational practices that make it easy to follow a reuse approach	43, 44, 45, 49, 59
Desirable	Reuse potential	Current artifacts that could be reused in a product line	33, 35, 47, 48, 50, 51, 52, 53, 54, 55, 56

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