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► **To cite this version:**

Ilya Yuskevich, Andreas Makoto Hein, Abdelkrim Doufene, Marija Jankovic. Model-based user experience-focused roadmapping. *Systems Engineering*, 2024, 10.1002/sys.21746 . hal-04436598

HAL Id: hal-04436598

<https://hal.science/hal-04436598>

Submitted on 5 Feb 2024

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Model-based User Experience-focused Roadmapping

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Technology roadmapping is an important yet challenging strategic process involving inter-disciplinary knowledge and requiring key decision-makers participation. To improve and facilitate this activity, a concept of model-based technology roadmapping has been proposed in the literature as an application of model-based systems engineering practices to the strategic planning domain. At the same time, many modern complex technical systems are required to be not only functional, efficient, and reliable, but also useful, usable, and desirable, which shifts the focus of planning to the user experience. In this paper, we developed a Domain-specific language that uniformly represents key concepts related to the four levels essential for strategic planning in the user-oriented business context: market, user experience design, engineering design, and technology. A collaborative interactive software was developed to support the proposed methodology. As a case study, a sustainable transformation of the automotive sector was tested and implemented in the software.

Keywords — Technology roadmapping, New product development, Model-based systems engineering, Domain-specific language, Strategic planning, Model-driven Engineering, User experience design

INTRODUCTION

The modern business environment compels companies to give the highest priority to the User Experience (UX) offered by their products and services. Strategic planning in these companies is extremely challenging (Kim et al., 2018). To survive and develop progressively, they should adapt their product line to diverse and constantly changing user needs, differentiate their

offer from the competition, anticipate and consider policy changes, the evolution of old or the emergence of new trends and technologies. In the literature, such a business environment is known as the VUCA-environment (Volatile, Uncertain, Complex, and Ambiguous) (Bennis and Nanus, 1986).

Strategic planning becomes even more challenging when products are complex systems. For example, automotive companies, on the one hand, deal with complex systems composed of many components and technologies; on the other hand, their domain is highly competitive, and their success links tightly to how well they address customer needs.

A technology roadmap is one of the most convenient and widely used instruments for developing and communicating strategic plans. A technology roadmap is a layered time-based chart representing an evolution of markets, products/services, and technologies (Phaal et al., 2004a). Technology roadmapping (TRM), the process of building a technology roadmap, has been performed over a long time in the industry and extensively studied in academia. Several drawbacks were identified during this exploration (Lee and Park, 2005; Albright and Kappel, 2003; Gradini et al., 2019; Kim et al., 2018).

In the context of the complex UX-focused systems planning, the two following problems are of particular interest. First, things rarely go as expected. Hence, there is a need to keep a roadmap alive, or, as (Gerdtsri et al., 2019) put it: ‘Get maintained’. This is especially true in the VUCA setting (Kim et al., 2018). When the environment is changing, the future is impossible to foresee and forecast. Second, roadmaps are typically performed at the coarse-grained strategic level and are often detached from the fine-grained tactical level of product and engineering design. Most roadmaps are only able to capture the most important user goals and requirements, abstracting out the details that may nevertheless influence the strategic level in case of complex systems design.

To overcome these difficulties, the concept of Model-based technology roadmapping (MB-TRM) was proposed (Golkar and Garzaniti, 2020; Knoll et al., 2018). MB-TRM is deeply rooted in the Model-based Systems Engineering, which facilitates the design of complex systems by offering better requirements traceability, better communication/information sharing, discipline-specific views, automated model configuration management, data persistency, etc. (Madni and Sievers, 2018; Campo et al., 2022; Henderson and Salado, 2020)

For the problem of roadmap maintenance, MB-TRM allows asynchronous, non-workshop-based procedures. Domain experts can work on their parts of the model at any time. Due to the formal syntax, changes are automatically stored in the common database and propagated to the other parts of the model. If conflicts (inconsistencies) appear, they can be resolved either manually (yet asynchronously) or automatically if corresponding rules are defined.

With regard to roadmap coherence and granularity, the roadmap is no more constrained to a static one-page layered chart format. In fact, a roadmap is not a chart anymore but a connected graph residing in multidimensional space (dimensions are, for example, time, business vertical, abstraction level, scenario). A viewer or contributor can see the roadmap in the various views and with adaptable levels of details depending on their needs, preferences, or permissions.

To build such an informational system, a Domain-specific language (DSL) is required. Therefore, the central question of this paper is which DSL to use. More specifically:

1. How can the syntax of known MBSE languages be tailored or modified to effectively address the problem of UX-focused roadmapping?
2. What can be the semantics of this DSL in the domain of interest?

Answers to these questions were elaborated iteratively in the course of this research. We propose to validate them with a case study. The success criteria are that designed DSL should correctly represent technology roadmapping (TRM) concepts and help to produce results aligned with what stakeholders expect to achieve with any TRM.

For the case study was chosen currently relevant problem from the automotive domain: shifting to vehicles with reduced or zero emissions of carbon dioxide. Although the case study is rather specific, the abstract concepts that we will explore

and develop are, we believe, applicable in a larger context: information technologies, telecommunications, urban planning, entertainment, just to name a few. Mid- and long-term evolution of any complex system or system of systems directly serving people can be conceptualized, formalized, and eventually managed using our methodology.

Moreover, a fully functional web-based tool has been developed to support the proposed methodology. The software implementation is important as it is a part of internal validation of research: it ensures the consistency of the methodology and allows to assess its usability.

This research is significant in a practical dimension. The proposed method holds implications for organizations seeking to effectively build and maintain their product strategic roadmaps. Authors hope, that by employing the proposed method, organizations can gain a comprehensive understanding of their ever-changing product landscape, and make informed decisions about product development and prioritization.

This research responds to the needs of the organization seeking to optimize its product strategy development process. The opportunity to address a real-world challenge while simultaneously advancing the MBSE field were two sources of motivation for this study.

The rest of the paper is structured as follows. First, we will review the literature on technology roadmapping. Then, we will introduce the proposed model-based UX design and roadmapping methodology. The previously discussed case study is presented in the section “Case study”. The final sections address the discussion and conclusions.

LITERATURE REVIEW

In the first part of this literature review, we discuss the main streams of research in the roadmapping domain. Afterwards, systems engineering and model-driven engineering domains are reviewed in order to highlight and support the needed DSL syntax.

1 Trends in technology roadmapping

Several systematic literature reviews were recently conducted in the TRM domain. de Alcantara and Martens (2019) and (Vinayavekhin et al., 2021) conducted a bibliometric analysis of the TRM body of literature, identified citation clusters, and major research streams. Kerr and Phaal (2020) provided an overview of the industrial practice over the last 30 years. Park et al. (2020) presented the results of a comprehensive study based on topic modeling, genealogical analysis, content analysis, and interviews, where they identified seven schools of thought in TRM.

The most prominent research field concerns the TRM development process. Kostoff and Schaller (2001) were the first who proposed to divide roadmaps into expert-based, computer-based, and hybrid. Twenty years later, Park et al. (2020) distinguished two schools of thought that form the theoretical basis for expert-based (or, more specifically, workshop-based) roadmapping, namely the Cambridge school, and for computer-based roadmapping, namely the Seoul school.

Scholars working on workshop-based roadmapping (Phaal et al., 2003, 2004b, 2011; Al-Ali and Phaal, 2019; Kerr et al., 2019; Kayabay et al., 2022) propose to develop a roadmap through a series of dedicated workshops, layer-by-layer (for example, market, product, technology, and then a workshop for integrating the layers).

In contrast, scholars advocating computer-based roadmapping (Kajikawa et al., 2010; Geum et al., 2015; Jeong and Yoon, 2015; Zhang et al., 2016; Miao et al., 2020; Nazarenko et al., 2021; Zhang et al., 2021), suggest building roadmaps in a semi-automatic manner by processing large textual databases (patents and scientific literature). Moreover, they argue that graphical user interfaces allow better visualization, component reuse, and customization (Lee and Park, 2005).

Structural and visual aspects of roadmaps were also considered by Cambridge and Seoul schools. (Phaal et al., 2004a) identify eight classes of roadmaps by purpose and six by format. (Kerr and Phaal, 2015; Phaal and Muller, 2020) comprehensively discuss possible roadmap architectures and visual styles. (Lee and Park, 2005) addressed the standardization and customization

of the digital roadmaps by proposing eight types of product and technology roadmaps.

Some contributions focus on establishing links with tools and processes from adjacent domains. TRM is naturally tied to decision-making. TRM integrated with Quality Function Deployment was studied by (An et al., 2008; Lee et al., 2013; Noh et al., 2021); with Analytical Hierarchy Process by (Jeon et al.; Lee and Geum, 2017); with Design Structure Matrix by (Son et al., 2018); with morphological analysis by (Bloem da Silveira Junior et al., 2018); with multiobjective optimization by (Aleina et al., 2017).

Two emerging approaches of TRM that were not included in the review of Park et al. (2020) are of particular interest to this paper. The first is so-called design roadmapping. It elaborates the link between TRM and User Experience Design (UXD) (Kim et al., 2018, 2016, 2017; Koens et al., 2021). The second one is Model-based Technology roadmapping (MB-TRM), an emergent research direction initiated by (Knoll et al., 2018). MB-TRM builds upon computer-based TRM, but differentiates from it by representing a roadmap and concepts included in the roadmap (technologies, products, markets) using some DSL. Gradini et al. (2019) argue that MB-TRM may substitute traditional (document-based) TRM in the future as it solves a number of its problems. Golkar and Garzaniti (2020) proposed a Model-Based Technology Roadmap Architecture that contains key components and processes of MB-TRM. Breckel et al. (2021) proposed a SysML based DSL for MB-TRM and applied it to the problem of strategic supply-chain planning in the automotive domain. Yuskevich et al. (2021b) complement MB-TRM with Pareto frontier forecasting and game-theoretic modeling. Yuskevich et al. (2021a) developed and validated a metamodel that describes most existing technology roadmaps at the abstract level.

The major research gap identified in the literature is outlined in the following. Kim et al. (2018) reasonably pointed out the need for agile UX-centered roadmapping and described its essence on a high level. In practice, the proposed process is arguably challenging. Agility within a workshop-based procedure is hardly achievable because, from the administrative point of view, it is hard to gather key decision-makers in one place regularly. The other challenge comes from the large data volume underpinning strategic decisions. This data needs to be effectively collected, stored, and analyzed. Therefore, a UX-focused TRM process needs to be asynchronous and computer-aided, which can be enabled by the MB-TRM proposal of (Knoll et al., 2018). However, the latter poses another problem of expressing such a vague and ambiguous concept as UX by some DSL, which was not addressed in the up-to-date literature. Therefore, the choice of the appropriate language is the main aim of this paper.

The final section of the literature review examines the syntax of general-purpose MBSE languages and concludes that none of them are well-suited for MB-TRM applications.

1 Candidate languages

Before we review candidates for the MB-TRM syntax, we identified the following requirements, which follow from the problem statement in the Introduction section:

1. The language shall be expressive and transparent for specialists of all four target fields: market/strategy, UX design, engineering design, technology. In other words, it should have a fast-learning curve. It means that the language should be composed of a relatively small number of generic and intuitively understood elements.
2. It shall explicitly support the assessment of the alternative decisions/configurations/scenarios (as roadmapping aims at helping to take strategic decisions).
3. It shall appreciate the transient nature of the UX, markets, products and technologies, and the hierarchical nature of user goals, use cases, system architectures, and technology taxonomies.
4. It shall have such a degree of formality that facilitates complexity management through automation and is able to generate insights (i.e., support some automated reasoning). This means that the language should not simply represent the concepts of interest but execute a certain set of operations over these concepts.

The first DSL candidate, the Systems Modeling Language (SysML) extends the Unified Modeling Language (UML). It has become a standard in the systems engineering domain (Huldt and Stenius, 2018) for expressing complex systems architectures. For each type of architecture (e.g., according to INCOSE (2015), physical and logical, which includes functional behavioral, temporal), SysML has a separate representation (diagram). Kotronis et al. (2019) have applied SysML for the assessment of UX-related metrics during complex systems design (namely, passenger’s comfort). The application of SysML for roadmapping was demonstrated in Breckel et al. (2021). In our opinion, these applications manifest several practical difficulties. The syntax of SysML is made specifically for complex systems architectures and is, therefore, bulky. It comprises nine views, with dozens of model elements in each. As a result, the practical outcomes of using UML (as well as SysML) in the real industrial context are often unsatisfactory due to misunderstandings and misuse (Bell, 2004). Moreover, UX designers and marketing specialists are not familiar with SysML. Due to the steep learning curve, they will require special training to use it (requirement 1). Finally, SysML does not include expressive elements to assess alternative configurations (requirement 2).

(Knoll et al., 2018) proposed an Object Process Methodology (OPM) for MB-TRM. OPM was developed by (Dori, 2002). An advantage of OPM is its minimal ontology (three types of entities and a dozen of links), that are in comparison to SysML easier to learn (requirement 1). The OPM syntax includes logical operations AND, OR, XOR (Wang and Dagli, 2013), which in theory should enable the assessment of alternative options (requirement 2). The latest versions of OPM are also executable (requirement 4) and support quantitative attributes (Dori et al., 2019).

Another option is Feature-oriented domain analysis (FODA), which was initially proposed for software product families modeling (Nešić et al., 2019). Due to its minimalistic notation, it is arguably one of the simplest modeling languages (requirement 1). In FODA, any model is a hierarchical directed graph (requirement 3) consisting of nodes (features) that can be mandatory or optional. Some nodes are organized into XOR groups (alternative decisions, requirement 2). Moreover, a few cross-tree constraints are defined, e.g., requires and excludes, which enables Boolean state propagation (requirement 4). Although the primary field of application of FODA is software engineering, this syntax was already successfully applied in the engineering design domain to new product development portfolio optimization (Abrantes and Figueiredo, 2014) and customer preference mining (Zhou et al., 2017).

A similar syntax was proposed in the non-functional requirement (NFR) framework (Chung et al., 2012). There, requirements are organized into so-called soft goal interdependency graphs (SIR), connected with logical links and XOR/OR/AND groups. In contrast to FODA, SIR supports quantitative links (referred to as negative and positive contributions).

Neither FODA/NFR, nor OPM support explicitly concepts of the UXD (requirement 3) without extensions that will be discussed later.

The table 1 summarizes how each candidate language addresses key properties identified for effective MB-TRM DSL.

As demonstrated in the table, general-purpose languages like OPM and SysML are ill-suited for roadmapping due to their inherent complexity, which, when applied to a specific domain, results in underutilized expressive elements. Moreover, they lack native support for variant modeling, long-term system evolution modeling, and automated reasoning. While workarounds can achieve these tasks, usability remains a significant hurdle due to a steep learning curve. In contrast, feature modeling language appears to be a good fit for roadmapping owing to its conciseness, high formality, and native support for variant modeling. However, it requires extensions to cater to the specific needs of model-based roadmapping.

MODEL-BASED USER EXPERIENCE DESIGN AND ROADMAPPING

This section will present the main elements of our approach: roadmap architecture, DSL syntax, and roadmap semantics.

	SysML	OPM	FODA
VARIANT MODELING	Indirect; through context blocks and stereotypes	Indirect; through stereotypes	Primary focus
TEMPORAL MODELING	Moderate; through state machines, activity diagrams, and parametric diagrams	Indirect; through state transitions and annotations	Indirect; can be achieved through time-stamped feature configurations
CUSTOMIZABLE ONTOLOGY	Moderate; through profiles and stereotypes	Moderate; through stereotypes and annotations	-
DEGREE OF FORMALITY	Moderate; not designed as a language of formal logic, supports certain logical operations	Moderate; not designed as a language of formal logic, supports certain logical operations	High; feature models can be expressed with statements of propositional logic
ROADMAP VIEW	-	-	-
SCOPE	General-purpose systems modeling language	General-purpose systems modeling language	Variability analysis, product family design
SYNTAX COMPLEXITY	High	Moderate	Low

TABLE 1 Comparison of candidate languages

1 Roadmap architecture

170

171 Yuskevich et al. (2021a) developed a metamodel of a model-based roadmap. This metamodel (see Fig. 1) describes a directed
 172 graph that is located in a three-dimensional space (level, time, and scenario). It represents all possible evolution scenarios of
 173 markets, products, and technologies (see Fig. 2).

174 All possible versions (or configurations) of market, product, or technology are contained within an *ElementClass* and
 175 specified by *Model*. A *Model* opens the 'fourth dimension' of a roadmap – abstraction hierarchy (Phaal and Muller, 2020) of
 176 various concepts. For example, user goals vary from high-level motivations to the elementary tasks; product features vary from
 177 high-level product-defining functions to the colors of indicators on a control panel, etc.

178 Each version of the market, product, or technology called *Element* is an instance of *ElementClass* (e.g., Tesla Model S is a
 179 product of electric vehicle class) and is specified by *ModelConfiguration*. *Elements* are shown in figure 2 as nodes of a graph.

180 This is the architecture of our roadmap. Now, the question is which syntax to use inside *Model* for representing *Elements*
 181 and *ElementClasses* (e.g. product features, aspects of UX, markets and technologies)? We chose to use homogeneous and
 182 straightforward syntax for all levels of the roadmap. As will be shown in the following section, this syntax is based on feature
 183 trees with some extensions. This was envisioned in Abrantes and Figueiredo (2014), who were apparently the first who proposed
 184 using FODA for NPD portfolio planning.

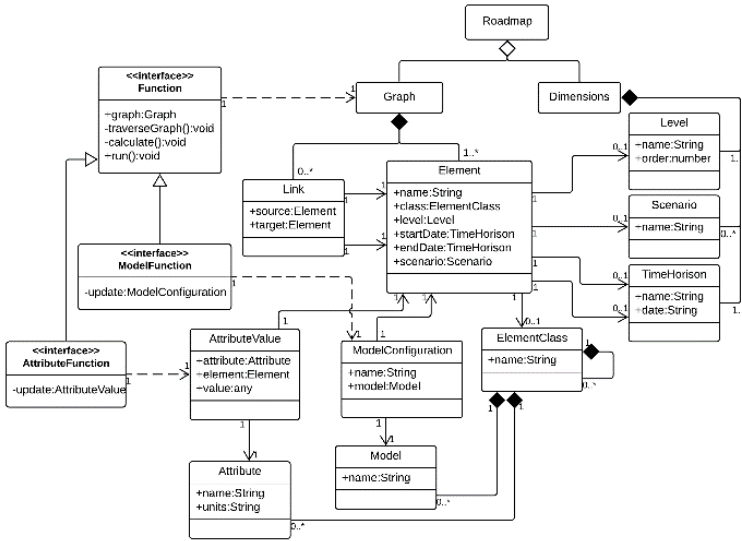


FIGURE 1 MB-TRM metamodel (Yuskevich et al., 2021a)

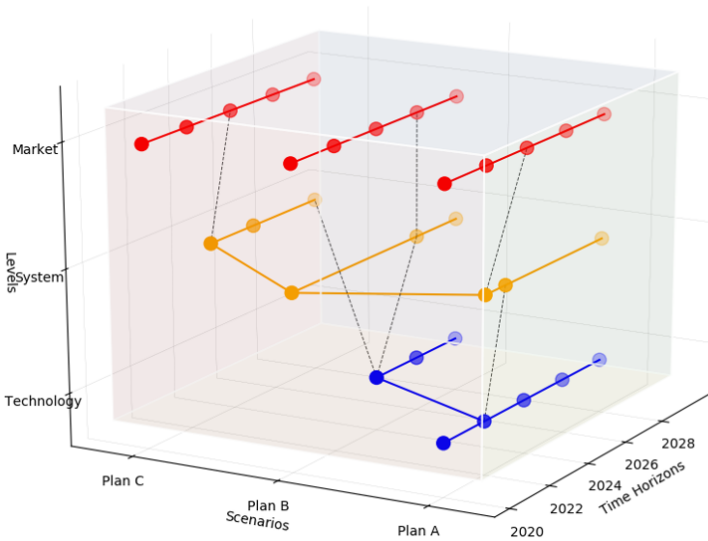


FIGURE 2 Geometric interpretation (Yuskevich et al., 2021a)

185 | **Domain-specific language syntax**

186 A FODA model representing the product can be seen in Figure 3. All concepts (components, functions, systems, technologies,
 187 and attributes) are modeled with a single entity – a feature.

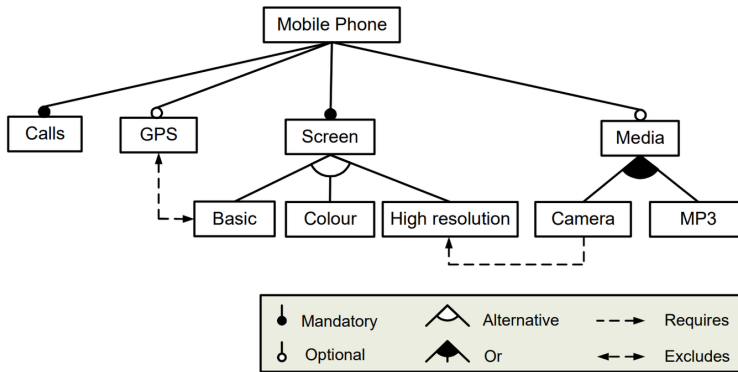


FIGURE 3 A sample feature model (from (Benavides et al., 2010))

188 The main value of feature tree syntax is in links. Links do not only have a descriptive purpose but also represent rules of the
 189 propagation of a boolean state – enabled or disabled. The feature model can be “configured,” i.e., a special mode allows a user to
 190 decide which optional features to include in a particular configuration.

191 Feature tree (a *Model*) represents all possible configurations, i.e., whole product family. Each instance of a feature tree
 192 (a *ModelConfiguration*), e.g., phone with basic screen and MP3, represents a concrete product. This mechanism allows for
 modelling product family evolution and market segmentation (Fig. 4).

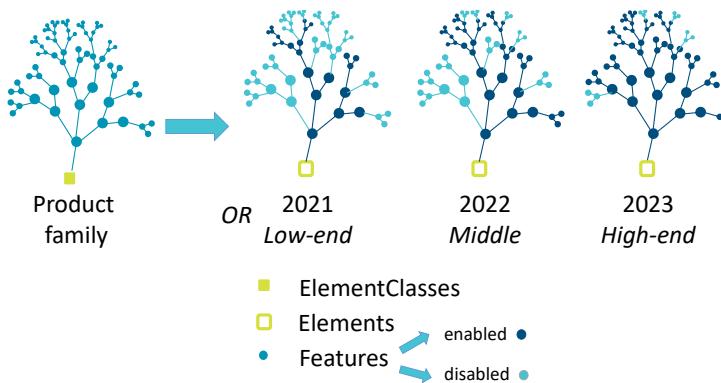


FIGURE 4 Product family evolution or segmentation with feature trees

193

194 However, in order to address the UXD and MB-TRM we propose several extensions of FODA syntax. First, we propose
 195 to add the notion of a *Subclass*, a modifier that classifies features. Unlike SysML and OPM, entities of the proposed DSL
 196 have customizable semantics (taxonomy for each aspect of a model can be defined in a separate view). Figure 5 illustrates the
 197 flexibility of an approach by expressing several concepts in SysML, OPM, and our DSL. In the UX design, activity, function, use
 198 case, as well as persona and user role have distinct meanings (requirement 3). This difference is lost in a plain OPM or SysML.
 199 Moreover, SysML possesses certain ambiguity (the same concept can be represented with different symbols depending on the

200 diagram/view). *Subclasses* can have parent-child relationships, so a user of a model can define custom taxonomies for each
 201 feature model.

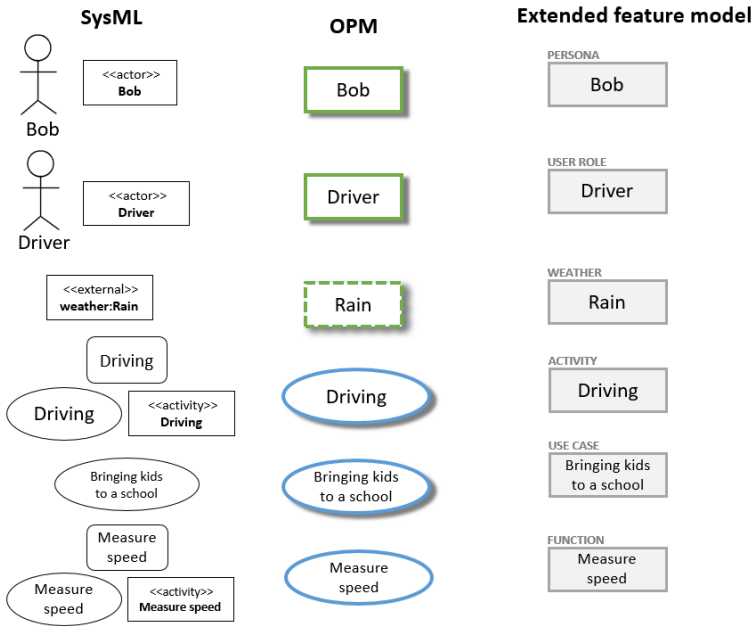


FIGURE 5 Comparison of proposed extended feature modeling syntax with SysML and OPM

202 Second, we propose to extend the ontology of cross-tree links. Except standard links such as *requires* and *excludes*, we
 203 propose to introduce *causes* and *equals* links. The logical operations that these links represent are defined in Figure 6, where
 204 means that feature is enabled, – disabled, ? – the state is unknown (both states possible). The left column stands for the cause,
 205 right – for effect.

206 These links (causes, requires, equals, and excludes) connect features that have qualitative meaning. For example, a goal
 207 ‘bring kids to school’ causes the use case ‘driving a car with kids’. An electric vehicle requires an electric traction motor. Having
 208 any car means that we also have (equals to) a goal ‘park a car’. The final example: living in a big city excludes free parking.

209 Additional two links were proposed by analogy with NFR framework (Chung et al., 2012) connects qualitative and
 210 quantitative features – *enhances* and *worsens* (Fig. 6). If a qualitative feature is enabled (e.g., a climate control system), a
 211 numeric score of a link is added to a quantitative feature (e.g., a comfort).

212

213 | **Semantics**

214 Semantics for the automotive case study is presented in Figure 7. At each level of a roadmap feature models in the left represent
 215 the qualitative aspect of a model, and in the right – quantitative. This figure represents also links between *Subclasses*. The
 216 direction of these links follows the decision-making flow. It goes from top to bottom (from markets to technologies) in a

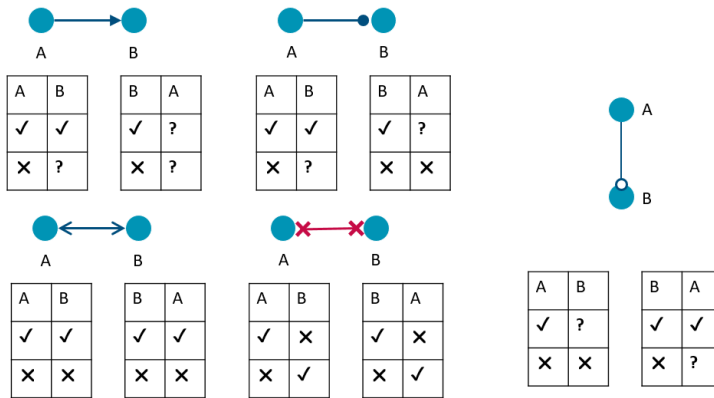


FIGURE 6 Cross-tree links syntax

217 qualitative axis (left) and influences quantitative metrics at each level (right). Then decision consequences propagate up on the
 218 quantitative axis (technology performances influence product characteristics, which influence UX-related metrics, etc.)

219 A literature review has been used for defining concepts proposed for the roadmapping.

220 Kim et al. (2016) distinguish 3 levels in the UX-focused roadmap: UXD, Product, and Technology. We propose to use
 221 this structure augmented by the marketing level due to its high importance for the automotive industry. On the marketing level
 222 a company may choose which market to target first – the low-end by pursuing affordability (a so-called low-end disruption
 223 rigid (Christensen, 1993)) or the high-end by pursuing functionality and product features (a so-called high-end disruption
 224 strategy (Dyer and Furr, 2015; Kilkki et al., 2018)). Markets are also segmented by region and characterized by market
 225 size (Hassan and Craft, 2005).

226 The UX design level impacts the strategy of a UX-focused business significantly and therefore requires special attention.
 227 Hassenzahl and Carroll (2010) and Pucillo and Cascini (2014) propose the goal-based model of UX. They argue that UX can be
 228 described through a hierarchy of user goals. On top of the hierarchy, there are high-level be-goals, e.g., “I want my kids to be
 229 safe.” On the lower levels, there are do-goals (e.g., “I will ensure the safety of my kid in the car”) and motor-goals (e.g., “I will
 230 double-check if the seatbelt is fastened”).

231 The concept of usage links UXD to engineering design. Just as goals, usage can be decomposed from abstract to concrete
 232 into a hierarchy of concepts. Alexander and Maiden (2004) define use cases “as a collection of scenarios,” which are the
 233 “alternative ways of achieving a goal.” Scenarios (not to be confused with strategic scenarios), in their turn, can be decomposed
 234 into activities and further into elementary tasks.

235 To measure the impact of product use, several models have been proposed in the literature. Usually, the following elements
 236 are distinguished: utility, usability, desirability (ISO 9241-210:2019, 2019), plus accessibility, creditability, findability, and the
 237 holistic measure called the value (Morville, 2005).

238 User experience designers also actively utilize personas and user roles (Cohn, 2004). The former should be considered a
 239 bridge between the marketing and UXD domains. In both areas, the concept of personas is commonly understood but is used
 240 with a different purpose.

241 The engineering design layer is domain-specific and classifies cars by body segment (mini, small, medium, SUV, etc), power
 242 train architecture (hybrid electric, plug-in electric, fuel cell electric, etc.). Architectural decisions taken in the left part of the
 243 model influence quantitative figures of merit (e.g., cost and performance) in the left side. This link was studied by (Selva et al.,

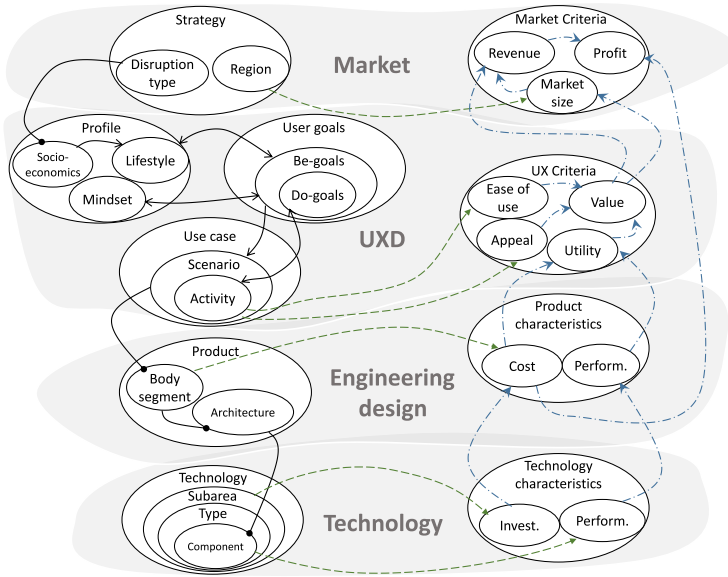


FIGURE 7 Case study-specific semantics (big ellipses represent *ElementClasses*, smaller nested ellipses – *Subclasses*)

2016).

The technology layer is composed of components classified by technology subarea and type as in (noa, 2019).

As the proposed approach implies flexible semantics, such a conceptual model may and should be designed for each roadmap separately, depending on specific needs. For example, for the selected case study, the UX design level is rather simplified. In the course of research, the authors also built a roadmap for the same automotive industry, but for the different product family, namely, Human-Machine Interfaces, where they considered more UX concepts, e.g., user role, external conditions (weather, time of the day), etc.

CASE STUDY

| Methodology

In the realm of Model-Based Systems Engineering (MBSE), case studies remain among the most favored validation tools due to their ability to capture rich and intricate contextual information and derive conclusions from practical results of a method under investigation. While other validation methods, such as controlled experiments and formal verification, offer their own strengths, particularly in establishing causal relationships, only case studies provide a holistic understanding of DSL applicability within its intended environment.

The case study was conducted within a real industrial context, specifically in the field of research and development of automotive Human-Machine interfaces, spanning three years. The research followed the traditional phases of design research methodology (Blessing and Chakrabarti, 2009):

- Problem identification in close collaboration with stakeholders
- Descriptive study I (state-of-the-art investigation)

- Prescriptive study (design of support tool)
- Descriptive study II (research evaluation)

Unfortunately, due to confidentiality restrictions, the results of the industrial case study cannot be disclosed. Therefore, the authors have created an alternative case study, free of commercial data, for illustrative purposes. This case study is intentionally kept simple to demonstrate the approach's internal logic and the DSL's expressiveness rather than building an industrial-grade roadmap.

A comprehensive discussion of the limitations and potential drawbacks associated with the chosen methodology will be presented in the limitations section.

General description

The case study represents an established automotive company that currently produces cars with internal combustion engines, aims to adapt to the recent market changes, and therefore strives to propose a product line with reduced CO2 emissions.

The company may choose two alternative strategies for entering these markets – low- and high-end. The markets are classified by geographical location – Europe, the Americas, and Asia, with different sizes in each segment.

UX designers have defined four personas, two for low-end and two for high-end market segments. Roberto lives in the suburbs, has kids, and possesses a traditional mindset. Alice is an eco-friendly person who lives in a big city. Kate has kids, possesses an eco-friendly mindset, and lives in the suburbs. Bob is a technology enthusiast who lives in a big city. Personas have different use cases depending on income, place of living, and family situation: daily commuting (with or without kids), long-distance trips, and occasional short trips. In the context of electric vehicles, the most important activity in each use case is parking because depending on equipment available on a parking lot, a user can or cannot charge it.

Four product architecture types may satisfy diverse personas' goals: hybrid electric, plug-in hybrid electric, battery-electric, and fuel cell electric. Cars are classified by body size segment: mini, small, medium, large, luxury, sport, and sport utility vehicle (SUV).

Depending on the chosen architecture, a company needs to invest in two technology areas: power train technologies (internal combustion engines, electric traction motors, fuel cells, and regenerative braking) and energy storage technologies (hydrogen and gasoline tanks, batteries, and supercapacitors).

Case study roadmap structure

The roadmap has two alternative scenarios depending on which strategy the company will choose. Low-end strategy is shown in Figure 8, high-end strategy – in Figure 9 (screenshots taken from our web-based software). Alternative strategies determine not only the target market segment (high-end or low-end), but also personas belonging to these market segments (Roberto, Alice, Bob and Kate), use cases, particular to these personas, and, eventually, products satisfying personas' needs (family hybrid, mini plug-in vs. luxury electric sedan, fuel cell coupe).

The feature model of the market strategy is shown in Figure 10. Figures 11-14 represent instances (configurations) of this model: low-end disruption (Fig. 11, 12) and high-end disruption (Fig. 13, 14) for two timeframes. The following figures represent personas general model (Fig. 15) and two of its instances: Alice (Fig. 16) and Kate (Fig. 17). Other feature models provided here in the paper without corresponding instances: use cases – figure 18; product family – figure 19; technology tree – figure 20.

When roadmap elements are defined, cross-tree links can be added (for example, Fuel cell electric vehicle requires hydrogen tank, having kids causes use case of bringing kids to school, etc.). The most convenient interface to link these multiple factors is through the DSM on the level of product-technologies and through the User journeys on the market-UXD levels (these interfaces

301 were also implemented in the software). Feature model of an *ElementClass* (for instance, a persona) represents all variants in one
 302 model (high or low income, has kids or not, urban or suburban habitant). The roadmap user (e.g., participant of a TRM sessions)
 303 needs to instantiate the model to represent a concrete persona (Roberto, Alice, Bob, Kate). These choices will not only specify the concrete instance, but also propagate changes in other parts of the model through the cross-tree links.

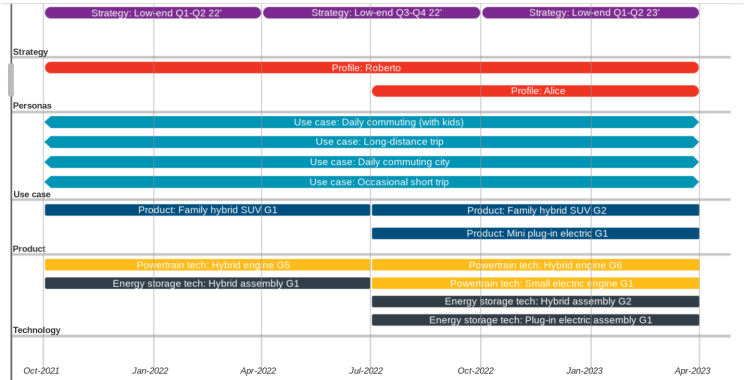


FIGURE 8 Low-end strategy roadmap

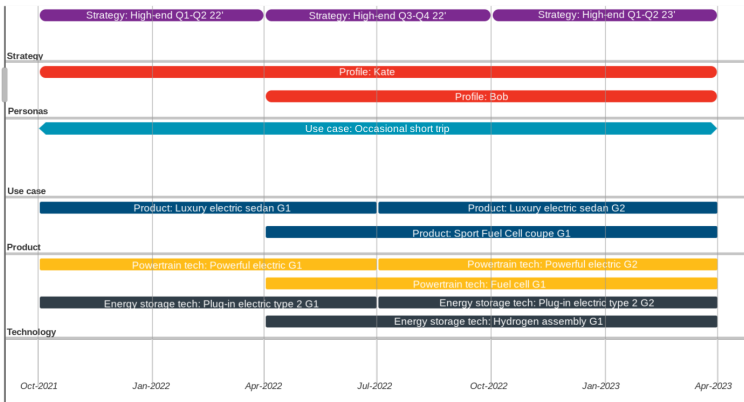


FIGURE 9 High-end strategy roadmap

304

305 ANALYSIS

306 As the proposed DSL is executable, roadmap contributors can analyze the key performance indicators, compare different
 307 scenarios and design options. The fact that such an analysis is cross-domain can be seen as a novelty of the proposed approach.

308 Figure 21 shows a global view, a composite feature model representing all concepts and factors in all its combinatorial
 309 complexity, from markets to technologies.

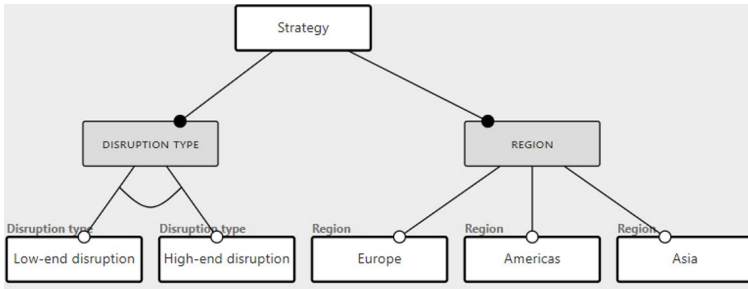


FIGURE 10 The feature model of the market strategies

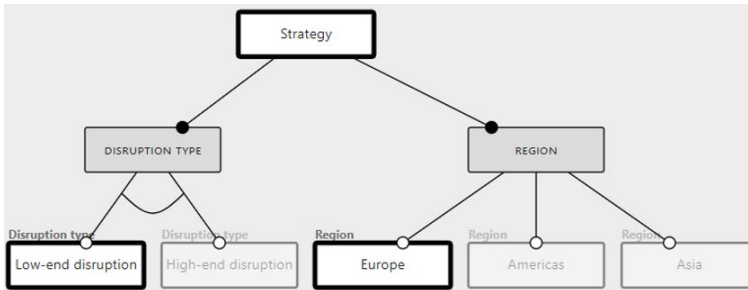


FIGURE 11 Low-end Q1-Q2 22'

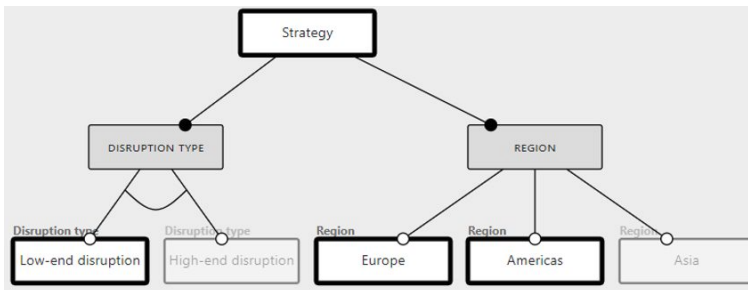


FIGURE 12 Low-end Q3-Q4 22'

310 This view shows how high-level (market and UXD) decisions reduce the decision space on the lower levels (product and
 311 technology) and how lower-level performance indicators influence higher-level figures of merit. Moreover, the model identifies
 312 inconsistencies, the configurations in which lower-level decisions contradict higher-level, or simply highlights logical flaws (e.g.,
 313 closed loops).

314 Specifically, figure 21 illustrates a chain of causes and effects going from markets to technologies and back. Environmental-
 315 ism causes changes in policy (tax on carbon emissions). A persona with a traditional mindset, not emotionally engaged into the

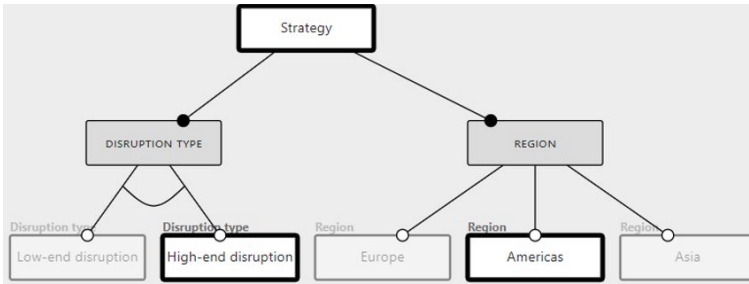


FIGURE 13 High-end Q1-Q2 22'

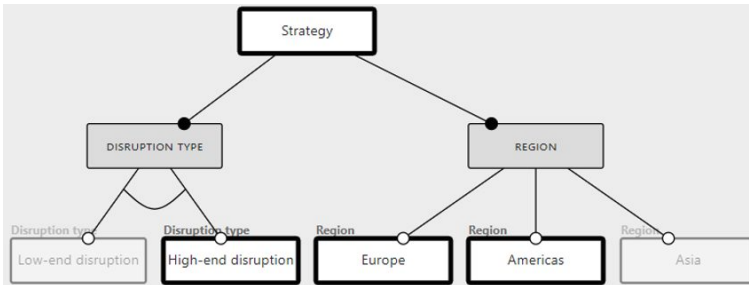


FIGURE 14 High-end Q3-Q4 22'

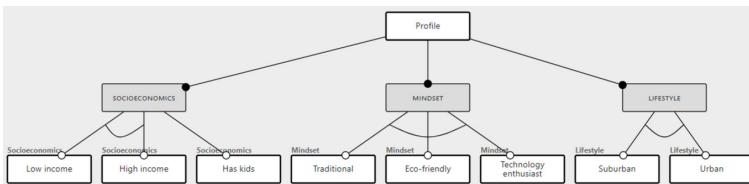


FIGURE 15 The feature model of personas

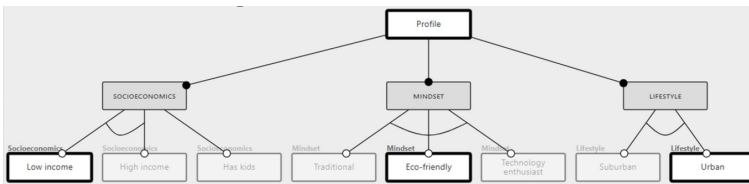


FIGURE 16 Persona: Alice

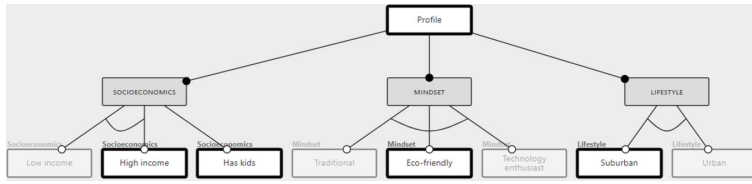


FIGURE 17 Persona: Kate

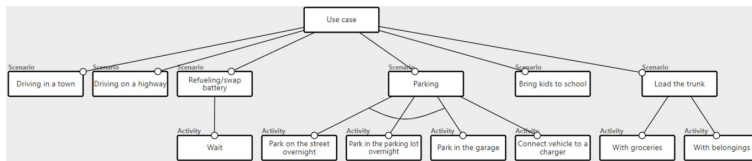


FIGURE 18 The feature model of use cases

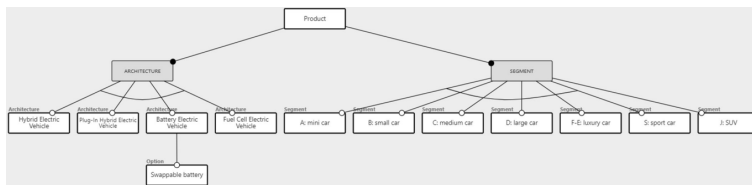


FIGURE 19 The feature model of product family

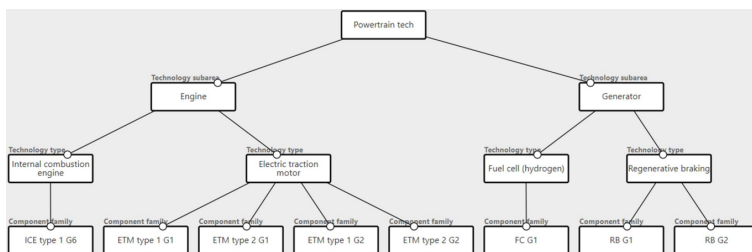


FIGURE 20 The feature model of powertrain technologies

316 topic of green economy, can nevertheless benefit from this policy change through a be-goal “I want a car with cheap maintenance.”
 317 The red dashed line signifies the negative effect of a tax on the UX criteria “Low gasoline spendings” (amplified by the necessity
 318 of bringing kids to school every day). Plug-in hybrid electric vehicle architecture requires “regenerative braking” technology.
 319 Then the quantitative links propagate back through criteria on multiple levels (regenerative braking -> regeneration efficiency
 320 (%)-> fuel consumption (l/100 km)-> low spendings on gasoline). The direct chain can be executed due to propositional logic

defined in the model (see Fig. 6); the backward chain is executed due to the extended syntax representing quantitative links.

Figure 21 also shows an exclusive link between the be-goal “Child-free” and the use case “bring kids to school every day”. This link opens an alternative instance of a model for persona with different motivations, use cases, UX criteria, etc. The benefit of the feature tree is that it represents all these possibilities in a single compact model.

Figure 22 shows an example of inconsistency (highlighted): a use case was selected that requires bringing kids to school for a persona with no kids. Figure 23 a) shows a given product’s calculated UX- and product-related metrics for a selected persona. Figure 23 b) shows the evolution of revenue and profit over time for one of the strategies.

Each bar on Fig 23 b) corresponds to the discrete-time (6 months each sequence). A single instance of a composite model (Fig. 21) can also represent each time sequence. For example, Figures 8, 9 show which specific markets the company targets at each time interval (for low-end strategy – first Europe, then Europe + Americas, for high-end – first Americas, then Europe + Americas). Additionally, product features, use cases, technologies evolve in time. Clearly, all these combinatorial variants will result in different technology and product characteristics, UX criteria, and, eventually, revenues and profits.

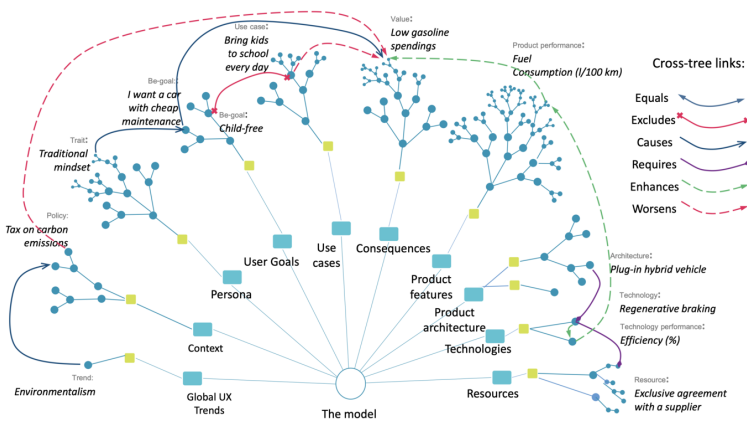


FIGURE 21 Composite feature model

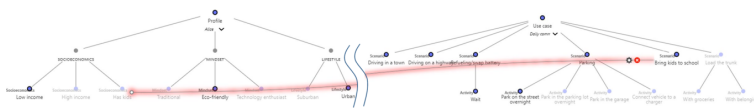


FIGURE 22 Analysis: inconsistencies identification

DISCUSSION

To our knowledge, the proposed approach is the only model-based strategic decision support tool that unifies and integrates such heterogeneous disciplines as marketing, UXD, and engineering. This is achieved by introducing simple yet powerful syntax based on feature models.

Following the existing industrial need identified in (Kim et al., 2018), this paper integrates the UXD layer into a roadmap.

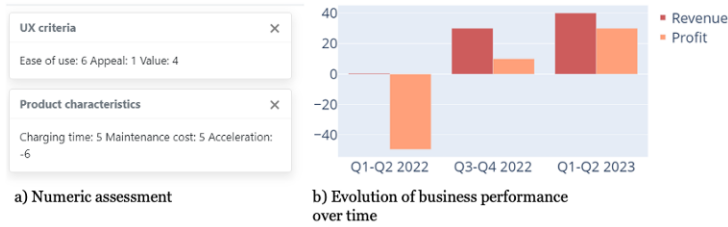


FIGURE 23 Analysis: Figures of Merit quantitative assessment

The objective is to focus on the end-user value and provide a better interface between marketing and product design concepts.

As was pointed out by (Knoll et al., 2018; Gradini et al., 2019), using formal languages for TRM has multiple advantages over the traditional document-based TRM in terms of improved accuracy, consistency and traceability, simplified collaboration, and offers various automations.

Specifically, software tools help to aggregate and manage effectively huge amounts of information. Therefore, the proposed approach enables more informed strategic decision-making by integrating information, which is not necessarily present in the strategic roadmap but is required to support evidence-based strategic decisions (e.g., personas' traits may not be considered as strategic information and therefore should not be displayed in a strategic chart, but they nevertheless underpin strategic decisions).

The proposed formal syntax aims to address the complexity of new product development. Due to the change propagation mechanism enabled by the feature model syntax, diverse teams can work on their parts of the model and be notified when inconsistencies are introduced.

Previous works (Zhou et al., 2017; Abrantes and Figueiredo, 2014) have proposed using feature models for new product development (NPD). Due to its model configuration mechanism, the feature modeling language facilitates combinatorial decision-making. In the context of NPD, it supports the automation of the assessment of multiple product alternatives and potentially enables the combinatorial optimization of products/technologies/resources. Using this configuration mechanism, strategist may follow the desired decision-making flow, such as 'market pull.' The decisions taken at the 'upper' levels of the model – market and UX levels – reduce possible alternatives at the lower levels of the model through cross-tree links propagating the effect further down.

The proposed approach is agnostic to the TRM process. A model-based roadmap can be designed during a series of workshops or, thanks to the consistency check mechanism, in an asynchronous manner. This improves the roadmap's maintainability and enables agile roadmapping.

This research has a number of drawbacks and limitations. First, we validated our approach to be consistent internally by showing that designed DSL indeed successfully represented target concepts, both in demonstrative and real-world use-cases. However, we did not assess the impact of the proposed method in real context, i.e., external verification with respect to what MB-TRM should achieve in its intended environment is missing. Even well-known model-based tools are prone to misuse. Therefore, utility and usability should be in the focus of future research. Second, we only considered MBSE languages in our study, although there are number of formal languages designed specifically for automated reasoning in computer science domain. Third, the proposed formal syntax with its binary logic goes against imprecise and fuzzy human reasoning which is in the spotlight in UXD. Therefore, boolean links can be generalized to Bayesian links, as in (Moullec et al., 2013). In this way, the effect will not necessarily follow the cause but appear with a certain probability (which reflects better the uncertain and ambiguous reality). Cardinality can be added as another possible extension of the syntax to represent physical architecture better.

CONCLUSION

In the practical dimension, this paper proposes a model-based approach for UXD and TRM that helps to integrate and harmonize marketing, design, product, and technology strategies. In the context of roadmapping, models help to build a concrete layer representing markets/UX/ products/technologies with the required granularity.

In the theoretical dimension, this research contributes to the emerging field of Model-based Technology Roadmapping (MB-TRM) (Knoll et al., 2018) and to a so-called UX-focused roadmapping (Kim et al., 2018) by developing a DSL based on feature modelling (FODA). In comparison to general-purpose languages, i.e., to OPM and SysML, the proposed syntax has several advantages. It is simple and, therefore, easy to learn. It expresses heterogeneous concepts in a unified manner. Additionally, it allows for quantitative and qualitative relationship definition, which models how qualitative decisions translate to quantitative outcomes and supports various analyses.

A Cloud-based collaborative platform was developed to support the proposed methodology. By doing this, we demonstrated the internal consistency and got an instrument that can be further studied (i.e., to assess the utility and usability in a real industrial setting).

However, further research is needed to evaluate its effectiveness in real-world settings and to address the identified limitations.

ACKNOWLEDGMENTS

Authors thank Prof. Alessandro Golkar and Prof. Olivier de Weck for the insightful discussions opening the direction for this research. Authors also thank IRT SystemX for supporting this research by providing funds and establishing industrial collaboration.

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