Variability Modeling for New Technology Choices in a Facility Management Domain

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Abstract. Today almost all activities in companies are supported by particular information systems. Emerging new technologies provide new opportunities for companies. However, the question arises, which of them and how should be combined with the existing technologies. In this paper the use of feature models is examined as the potential methodological basis for answering the question on new technology choice. The information systems in Facility Management domain are considered. The paper gives an overview of traditional and relatively new technologies used in Facility Management and shows how these technologies are organized in feature models to help to find the best options in new technology choice.

Keywords: Facility Management Technologies, Variability, Feature Model.

1 Introduction

Emergence of new technologies raises the question of compliance and compatibility of these technologies with those technologies that are already used in enterprises. Also, it is important to choose the right combination of technologies if a new company is created. There is a high variability of possible combinations of technologies [1], [2] which promotes to assume that variability management methods might be applied to help do the right choices. This paper reports on experiments that were made with the purpose to find a methodological basis for choosing new technologies that can be well combined with the existing ones for utilizing the existing and new technologies in an effective way. The experiments were done in the domain of Facility Management (FM) with application of variability management approaches; namely, feature models were created to support the choice of technologies. The experiments were made to answer the following research question "Can variability modeling in general and feature models in particular be useful in choosing technology combinations in the domain of facility management?".The following method was used for the experiments. First, the information on existing and potentially new facility management technologies was amalgamated (see Section 2). During this process the technologies were grouped according to the main categories of FM functions at the category and function levels (due to space limitations, the mappings between categories, functions, and technologies are not shown in detail in the paper). The mappings were made in order to amalgamate knowledge on FM technologies in the form applicable for variability modeling. Further the mappings and additional groupings of technologies were used to construct the feature models. Brief introduction in variability modeling is given in Section 3. The feature models are presented and discussed in Section 4. Brief conclusions are available in Section 5.

2 The Spectrum of Facility Management Technologies

The knowledge on FM technologies is dispersed that hinders both: its amalgamation and the use of variability modeling techniques. However, if a variability modeling is to be applied onto some knowledge, this knowledge must be made available, navigable (i.e. structured), changeable and extendable. Thus the necessary first step was amalgamating and organizing knowledge on FM technologies. The analysis of the spectrum of existing FM technologies was based on the main categories of FM functions suggested by Talamo and Bonanomi [1]. These are AC–Accommodation (space), WP– (workplace (working environment), TI–Technical infrastructure (utilities), SS–safety and security management, CL–Cleaning (hygiene and cleanness), OU–Outdoor (land, site, lot, parking), HSS–Health, safety and security, HO–Hospitality (support for hospitable working environment), ICT–Information and communication technologies, LO–Logistics (transport and storage of goods and information), and OSS–Other support services. Each of these categories amalgamates several FM functions.

Nine standalone "classical" technologies were identified (abbreviated as CAFM, IWMS, CMMS, BMS (BAS), BEMS, BIM, RFID, GIS, and CAD). These are briefly characterized below to show how ambiguous and hard it is to structure knowledge on the technologies. In the analysis, knowledge on these technologies was organized at the level of their sub-categories in large tables (not possible to show them here) that later were used in creation of variability models.

CAFM – Computer Aided Facilities Management systems is considered as the core Facility Management information systems [2]. The general aim of CAFM systems is to reduce costs while improving efficiency. They support processes in space management, technical infrastructure management and workplace management. The CAFM system can be thought of as a system consisting of different modules that all have different purposes, functions and outputs. It pairs together with platforms that support facility management, space management and reactive maintenance, e.g. work order systems and CAD (computer aided design) facility plans. It is a step up from Computerized Maintenance Management System (CMMS) and spreadsheets [3]. CAFM systems offer advanced analytical tools for performance and efficiency evaluation based on technical, spatial and financial data, such as energy consumption, space occupancy and maintenance information [4]. The gathered information can be used to monitor and track critical equipment and key performance indicators (KPIs) for cost, operations and maintenance, space; and to handle other critical information [3]. The CAFM software provides multiple tools to plan and budget, manage and record utility usage, while also aiding tasks such as logging requests and maintenance plans, and assigning employees to rooms [4].

CMMS – Computerized Maintenance Management System is used for managing work orders and assets, keeping employee records, generating service requests and tracking and calculating used and required resources for jobs [5]. It also provides preventive and planned service maintenance and is used to schedule and record equipment-related planned maintenance activities [6]. The CMMS can monitor the operational level, provide updates, and generate work order requests for any piece of equipment if the maintenance conditions are not satisfied [7], [8]. The work order information including date, performance and expanded man-hours is usually stored in a database for further usage and analysis. The generated work orders can also be prioritized [6]. The core maintenance management software activities, facilitated by CMMS include [7], [8]: equipment/asset records creation and maintenance; equipment/asset bill of materials creation and maintenance; equipment/asset and work order history; inventory control; work order creation, scheduling, execution and completion; PM plan development and scheduling; human resources; purchasing and receiving; invoices matching and accounts payable; and tables and reports.

IWMS – Integrated Workplace Management System covers the same facility management function areas as CAFM, but has a broader scope [9]. The term IWMS was defined by Gartner in 2004 as an enterprise-class software platform integrating five key components: Asset & Maintenance management; Facilities and space management; Real estate and lease management; Environmental sustainability; and Project management. IWMS maximizes the usefulness of all assets and resources within an organization by sharing information using an integrated software platform [10]. CAFM shares a lot of similarities with IWMS when looking at the tools that it provides to the facility manager. IWMS systems can contain staff and department identification data, space and security level access data, income, leasing, and information about tenant chargeback.

BAS (BMS) – Building Automation System also referred as Building Maintenance System (BMS) is a control system and a network of sensors and devices [9] that control and monitor a wide variety of systems, such as [11]: Heating, Ventilation, Air Conditioning (HVAC); power generation; lighting; CCTV; access control; safety; and security. BAS is a key component in building infrastructure [12]. It contains a significant quantity of detailed, up-to-date and precise data [4], and aids building operators and chief engineers in their day-to-day work. The devices integrated with BAS can be monitored, queried and remotely controlled which makes them a powerful asset in FM infrastructure [4]. Even though BAS is considered to be a key asset in FM [12], it lacks the analytic insights that CAFM and IWMS provide [2].

BEMS – Building Energy Management System is a monitoring and control system that uses the existing building infrastructure data to analyze and visualize the data to aid facility managers [13]. BEMS uses multiple data sources for analysis and visualization, such as HVAC, security, and safety systems data while also using utility, dynamic price signal, demand response event and energy tariff data. It can also be integrated with CAFM and BIM systems [8], [9].

BIM – Building Information Modeling is a term that is ambiguously defined. It is defined by professionals in at least three different ways [14]: as a software application; as a process for designing and documenting building information; and as a new approach to practice and advance the facilities manager profession by implementing new contracts, policies, and relationships among stakeholders. BIM generates and manages digital representations of facility characteristics in 3D. The resulting representations are used to make decisions about the facility processes throughout the facility life cycle. It is used in both construction and design as well as facility refurbishment [9]. BIM also solves the challenge of integrating the design and construction stage data with the currently relevant data [15].

RFID – Radio Frequency Identification is a technology that uses electronic tags to collect data [9] and track the location of assets and people in real-time. RFID chips can be used together with sensors, e.g., for analyzing energy usage by detecting air flow [8], [9]. RFID chips work by transmitting the stored data that it has collected to a reader or a remote sensor using a microchip with an antenna. The chip itself is attached to a piece of equipment or infrastructure that requires tracking and is powered by the device that reads the data [9], [12]. The RFID technology is widely used in different FM domains, such as [16]: inventory; building energy controls; security; construction site delivery logistics; material tracking; document tracking; and product lifecycle tracking.

GIS – Geospatial Information System also referred as Geographic Information System is a system consisting of information, data and software about the geography of objects and relationships between them [17]. GIS is used to track staff, vehicles, assets and other critical objects in sites and buildings. It can be characterized by the combination of database, analysis, cartography and statistical technologies [9]. It is used in FM to process the geographic data by capturing, storing, manipulating, analyzing and presenting the data. The gathered data also aids the facility managers in the following activities [9]: space management; planning; visualization; and emergency and disaster planning and response.

CAD – Computer Aided Design system is an extension of the architectural floor plans which is the standard for built environment overview [17]. It is used by the designer to create, modify, analyze, and optimize a design [9]. CAD drawings are in between architectural floor plans and BIM in the evolution of building representations which essentially progress from a single floor to whole building views [17]. While GIS is used to manage entities across the buildings and sites, CAD is used for construction and design; therefore GIS is not intended to replace CAD [17].

As can be seen from technology descriptions above, the used technologies are overlapping in different categories. The FM functional category TI (Technical infrastructure (utilities)) is supported by all of the selected technologies (CAFM, IWMS, CMMS, BMS (BAS), BEMS, BIM, RFID, CAD, and GIS).

To simplify distinguishing between these technologies we, based on related work, [18], grouped the technologies by their focus. This grouping gives an overview of technology overlap between Facility Management categories. Here the reviewed technologies are grouped by their focus as follows:

- Data repositories – GIS, CAD;
- Facility intelligence – BEMS, BMS/BAS;
- Mobile/sensors – RFID;
- Workflow – CAFM, CMMS, IWMS.

These technology focus groups are used further in variability modeling (Section 4).

Besides above discussed base technologies used in FM there are new technologies changing the way how buildings and workplaces are managed. Digitization in recent years has become a hot topic for building industry. It makes it more agile, integrated, and responsive [19].

We found six literature sources which included important information referring to the ‘new technologies’ and technology trends in FM. These sources are listed in Table 1 by their source identification number (SID), title, authors or publishers, and the publication year. Analysis of these sources revealed eight different new technologies that are listed in Table 2 that shows which technologies are mentioned in which source.

Table 1. FM new technology sources.

Source ID	*Title*	*Author / Publisher*	*Year of publishing*
SID1	Top trends in facilities management. How society, demographics and technology are changing the world of FM	CBRE	2017
SID2	Revolutionary Technology Trends	AkitaBox	2016
SID3	Strategic facilities management RICS guidance note, global, 1st edition	Alan D White (RICS)	2013
SID4	Top Tech Trends for FM – 2017	Service Works Global	2017
SID5	Technology Innovation Set To Transform Facilities Management	Ben Howden	2017
SID6	Digitization. The key to maintaining a competitive advantage in Enterprise Facilities Management	Hannah Hahn, Duncan Sheehan (CBRE)	2016

Table 2. New Technologies.

Source	*New technologies*							
Source ID	*IoT & smart devices*	*Wearable technology*	*Big Data*	*Virtual Reality Buildings*	*Robots & Drones*	*Mobile applications*	*Integration*	*Smart Buildings*
SID1	✓		✓		✓		✓	✓
SID2	✓	✓	✓	✓	✓			
SID3							✓	
SID4	✓	✓	✓			✓	✓	✓
SID5	✓		✓		✓	✓	✓	✓
SID6	✓		✓		✓	✓		✓

Most of the technologies listed in Table 2 are already widely used in different fields, but are relatively new in FM. Not all of the reviewed technologies can be implemented and used in FM as a standalone solution. For instance, IoT sensors and devices can be easily integrated into the building. To gain the best from them, the facility maintenance software must be present. Additionally, a must have requirement is the ability to process the gathered information from the installed sensors: lighting, occupancy sensors, PPL (plug and process load) energy usage utilities integrated in the office equipment machines, such as computers and monitors, coffee machines, vending machines and other equipment. A powerful business analytics tool is required to use the data. Smart building management differs from older building management because most of the necessary technologies are already built in and they can be managed in a centralized way using one or more facility management systems, such as CAFM and BIM. Implementing new supporting technologies is easier because of the integration support. Integration is reviewed as well, because applications and systems in various areas of FM use different management and maintenance systems. Integration systems bridge the gap between multiple technologies and improve the management process workflow in general while avoiding data redundancy. One of the most discussed technologies which can reach the expectations of a fully integrated FM system is BIM [15]. Even though BIM has its roots in Construction Management, its functionality can be applied almost in all phases of FM. In Table 3 new technologies are cross-mapped with existing technologies that, according to the literature reviewed, can support their implementation. Information from this table is used further in Section 4 to create feature models and identify the constraints in these models.

Table 3. Existing technologies supported by new technologies.

Existing technology	*IoT & smart devices*	*Wearable technology*	*Big Data*	*Virtual Reality Buildings*	*Robots & Drones*	*Mobile applications*	*Integration*	*Smart Buildings*
CAFM	✓	✓	✓			✓		✓
IWMS	✓	✓	✓			✓		✓
CMMS	✓	✓	✓			✓		✓
BAS	✓	✓	✓		✓	✓		✓
BEMS	✓	✓	✓		✓	✓		✓
BIM	✓	✓	✓	✓	✓	✓	✓	✓
RFID	✓	✓	✓					
CAD	✓	✓	✓	✓	✓			
GIS	✓	✓	✓	✓	✓			

3 Variability Modeling

Variability modeling is used for handling high complexity of, e.g. flexible and configurable software systems. In this research, we use variability modeling to show the new technology applicability in FM in order to represent possible variants of technology combinations. This section gives an insight into the variability handling approaches.

Variability is understood as the ability to create system variants for different contexts of use [20]. Those variants are so called artifacts or components that are changed to fit in a specific context [21]. There are two main areas of variability management application. The most studied domain of variability is in software product line (SPL) management [20]. Another popular domain for using variability management is service systems engineering [21].

According to [22] “a Software Product Line (SPL) is an approach to software reuse in the large where a set of related software systems is perceived as a software family consisting of a common core and variable parts often referred to as features.” All members of the SPL share these common parts and each product has its own particular parts. Commonality is mainly defined during the product line scoping, but variability must be modeled through every SPL development phase (requirements analyzing and design). When the product is ready to be implemented, the variability is finalized. Different types of variability exist that need to be considered. Technical variability focuses on “how” a product line can be implemented. Functional variability focuses on “what” the product line should be capable of. Variants (products) are created by combining common core with the functionality associated with a set of selected features. It is not always possible to do a combination of features due to business constraints or technical incompatibilities.

Service variability is the ability of service (or process) to be efficiently extended, changed, customized or configured for the use in a particular context. Service variability brings out customizable services in service ecosystems. Service customization activated by a consumer will result in a particular service variant matching the consumer’s requirements [23].

To represent variability, variability models are used. The approaches to model and manage variability are classified into three main branches: feature-oriented methods, object-oriented methods, and integration methods.

Variability modeling using object-oriented approach includes two main steps – a kernel domain model is completed and variations of the domain are analyzed. Objects in the model can be kernel, optional or variant objects. The relationship between the objects can be applied as: (a) aggregation hierarchy – supporting the IS-PART-OF relationship; (b) generalization/specialization hierarchy – supporting the IS-A relationship; and (c) feature/object dependencies – showing the objects required to support each feature of the domain.

In variability modeling using feature-oriented approach, variability is analyzed based on variability requirement model. A variability design model is then created after the analysis. This model provides a detailed design and component construction. The main focus is on identification of concurrent processes and domain-oriented common modules allocating the features, functions, and data objects defined in the domain models to the processes and modules. If the constraints for validation after the feature model customizations for the specific application are to be satisfied, constraint relationships between variable features are used. The relationships between features are represented as [24]:

- composition or generalization relationships;
- dependency relationship;
- exclusive and non-exclusive alternatives and mutual exclusion relationship.

In variability modeling using an integrated method, the aim is to improve both the feature-oriented method and the object oriented method. One of the examples is Reuse-Driven Software Engineering Business (RSEB). The RSEB is a use-case driven systematic reuse process: architecture and reusable subsystems are first described by use cases and then transformed into object models that are traceable to these use cases [24]. Structuring of use case and object models using explicit variation points is captured in the RSEB variability. Based on the notion of ‘domain-oriented’, it emphasizes a group of closely related applications in a domain rather than a single application, but first a domain use case model is created. The relationships between features are represented as: the alternative relationship – variation and variant features; and as the binding time – attribute of vp-features. Vp-features can be bound at reuse time, i.e. when the re-user accesses the domain infrastructure to configure the reusable assets for development [24].

Variability modeling can be applied almost for every system where variations are present. Different approaches are used to define and set variants. The models presented in the next section utilize experiences from variability modeling in service systems and software engineering. Variations are modeled using Feature oriented approach.

4 Variability Models for Facility Management Technologies

In this section, variability models based on categories of existing base FM technologies and new technologies are created in order to help to reveal which technology combinations are most appropriate in particular cases. The models are represented by a detailed description and a set of constraints that are based on Table 3 (see Section 2). The models represent Facility Management categories supported by existing and new technologies as features. Two types of categories are distinguished – abstract categories (represented as variation points in light rectangular boxes) that are implemented by concrete categories (represented as variation points in dark rectangular boxes). Below we show and discuss some of the created models.

Model A (see Fig. 1) depicts the possible technology variations for the Accommodation Facility Management category. It includes the existing technologies related to Accommodation management and maintenance – CAFM, IWMS, CMMS, BIM, CAD, GIS – and the identified new technologies – IoT, Big Data, Mobile applications, Smart Building, Robots & Drones, Wearable technologies and Virtual Reality. The constraints added to show the links between the existing and the new FM technologies are shown beneath the variability model.

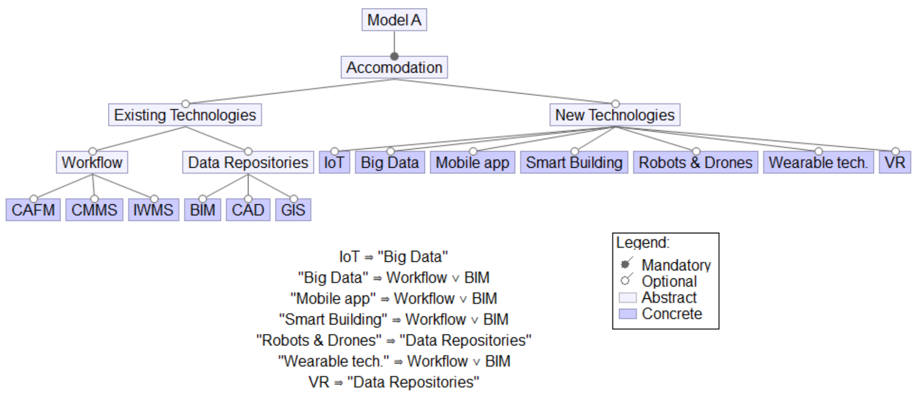

Fig. 1. Model A.

The constraints show that Big Data covers the same new technologies as IoT and is mandatory when IoT technologies are implemented. The output of IoT sensors and devices is in the form of data that can be further analyzed by technologies that support Big Data. Redundancy between the new technologies can be observed – Big Data, Mobile app, Smart Building, and Wearable technologies are supported by the same existing technologies.

Workplace Facility Management category variability model is represented by Model B (see Figure 2). Existing technologies related to Workplace management and maintenance are CAFM, IWMS, CMMS, BIM; and the identified new technologies are IoT, Big Data, Mobile applications, Smart Building, Robots & Drones, and Wearable technologies and VR. The constraints added to show the links between the existing and the new FM technologies are shown beneath the variability model.

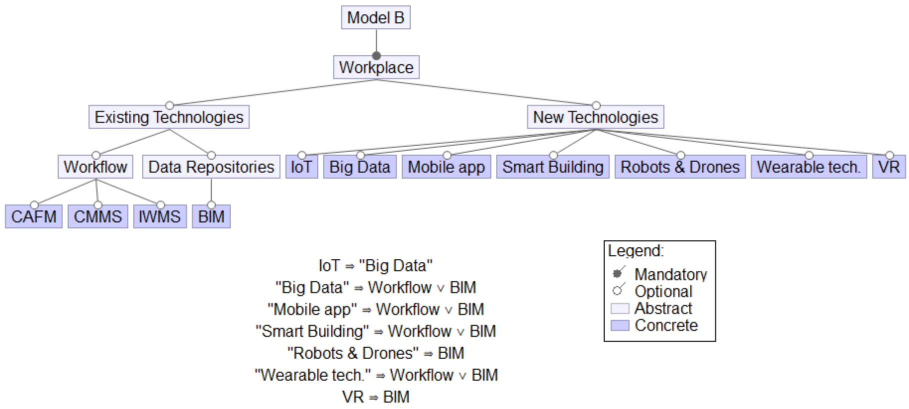

Fig. 2. Model B.

Comparing with Model A (see Figure 1), Model B includes all of the technologies seen in Model A. This is because the Workplace category is supported by the same existing technologies as Accommodation.

In a similar way models were created for other functional categories: Technical infrastructure, Cleaning, Health, safety and security, and other functional groups. By analyzing the developed models, it was concluded that this level of category abstraction is too low. The models are useful only in cases when we want to have an overview of the FM technologies and see which existing technologies support the provided new technologies.

To get a better understanding of the applicability of new technologies we developed variability models from a different perspective where each category is divided by its supporting functions. New technologies are assigned for each function. The new technologies represented in the models show for which particular functionality it can be used. The absence of a technology in models does not mean it is not applicable. The represented technologies are chosen by considering their relevance in the models. Model A1 (see Figure 3) represents category Accommodation and its functions identified during the literature review (ACF1–Strategic space planning and management, ACF2–Programming and briefing, ACF3–Design and construction, ACF4–Lease and occupancy management, ACF5–Building operations and maintenance, and ACF6–Renovation and/or refurbishment) separately.

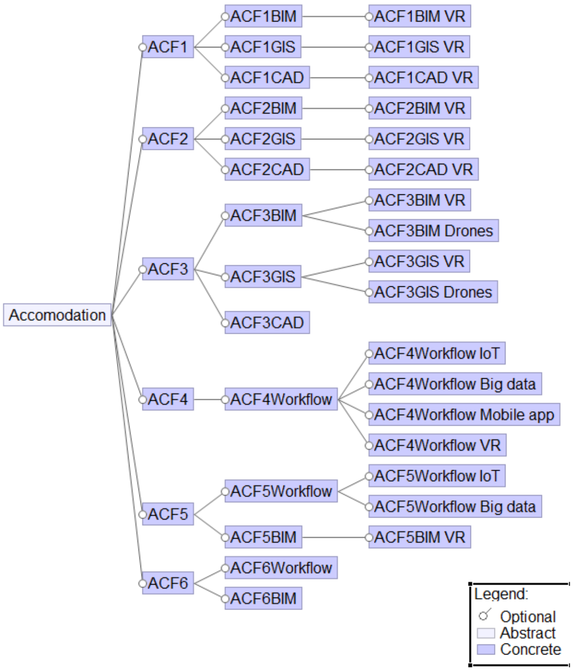

Fig. 3. Model A1.

Each function is supported by existing technologies. CAFM, CMMS and IWMS are grouped and represented as abstract technology category “Workflow”. This is done to keep model readable. Every function can be supported by appliance of new technology. This facilitates understanding which new technologies are appropriate for the main category (Accommodation) and it shows which functions could be improved using new technologies. For instance, function ACF4 (Lease and occupancy management) is managed by “Workflow” technologies. CAFM, CMMS and IWMS are responsible for maintaining the functions of ACF4 tasks, such as monitoring of physical spaces. New technologies, such as IoT, Big Data, Mobile app and VR, are applicable. Regarding to each technology, physical space monitoring can be improved; for instance, by applying IoT and sensors or devices that are capable to determine if the physical room is occupied or is it free. Data gathered from the monitored places allows applying Business Intelligence and analyzing the occupancy and waste of space patterns and tendencies.

Similarly, more detailed variability models were created for all other main functional categories of FM.

The experiments reported in this paper show that variability modeling can be applied to help to select the most appropriate technology combinations. Two different perspectives were used to visualize the data. One perspective is very general. The user of the model can identify the existing and the new technologies which are appropriate for a specific function category. The developed models (A and B shown as an example) are only a part of the solution. To get a better insight about the appropriate technologies – the data was visualized from another perspective (Model A1). This viewpoint is more detailed and specific. Each function of a particular base technology category is related to its supporting existing technology giving a deeper insight into the technology combination.

5 Conclusions

The research discussed in this paper let to give a positive answer to the research question "Can variability modeling in general and feature models in particular be useful in choosing technology combinations in the domain of FM?". The feature models, based on abstract categories of technologies are useful in cases when we want to have an overview of the FM technologies and see which existing technologies support the new technologies. For a more detailed view, function oriented feature models can be developed.

The result was achieved by deep analysis of IT solutions in FM domain. The main difficulties were related to different levels of abstraction and granularity in technology descriptions and overlapping capabilities of technologies. The further work concerns addressing these difficulties by developing dedicated knowledge management methods and feature modeling tools.

This work is limited to FM domain. However, the experience gained in the experiments can also be useful in other domains. It shows that for being able to apply feature models for technology combination identification, deep analysis of technologies applicable in the domain is needed. In this work the distinction between base and new technologies was applied. However, continuous technology change monitoring methods are to be developed to keep this distinction up to date.

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