

## Architectural Characteristics of Digital Services Enabled by Embedded Technology: A Study on Remote Diagnostics Services

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### Abstract

*In this paper, we characterize the architecture of digital services that are enabled by embedded technology. Digitalization with embedded technology in physical products has become a common phenomenon. In spite of growing instance of such digitalization, little is known about the architectural characteristics of embedded technology enabled digital services. Based on a research on vehicular remote diagnostics services, we characterize the architecture of such digital services. Following the framework on layered modular architecture continuum, our findings provide the following architectural characteristics: i) the architecture of the digital services spans along the layered modular architecture continuum, ii) the application program of the digital services is simultaneously de-coupled and partly coupled with the embedded devices, iii) there exist layers within layer of the digital services, iv) application program layer of the digital services is a closed innovation platform.*

### 1. Introduction

The digitalization of vehicles is rapidly increasing due to the development of embedded information technology that enables digital services. This digitalization of vehicles brings significant changes in the business of vehicle manufacturing firms. These changes are related to the architectural characteristics of digital services. Thus, it is of interest to inquire into the architectural characteristics of digital services.

Previous research has explained the architectural characteristics of physical products as well as service processes with the help of modular architecture [1, 2, 3, 4]. A modular architecture exhibits one-to-one mapping between functional elements and physical modules [3]. Digitalized products and services cannot be understood merely with the help of the modular architecture as modular architecture does not explain the transformational potential of digital technology.

Digital technology is continuously connecting the previously unconnected product components [5]. Studies have also been conducted to understand the architectural characteristics of digital artifacts and services through layered architecture of digital technology [6, 7]. Layered architecture has become more broadly applicable for all digitalized products. However, continuous digitalization of industrial products creates new architectural characteristics [8].

The transformation potential of digital technology is discussed by Yoo et al. [8] while presenting a conceptual framework called layered modular architecture continuum for digitalized products or services. Nowadays, digital innovation is taking place in different ways. The phenomenon of embedding digital devices in previously non-digital products such as vehicles is changing the products to a large extent. Due to the embedded digital technology, a physical product has become a medium for service provision. Pointing to the phenomenon, Yoo et al. [8] urge for research in understanding the architectural characteristics of the products or services enabled by embedded digital technology. Continuous digitalization of non-digital products are changing their architecture, giving them new meanings and affecting the business. Hence, studying the architectural characteristics of such digital services can shed light on this phenomenon of digitalization.

In this research, we investigate the research question, 'What are the architectural characteristics of digital services enabled by embedded technology?' To answer this question, we conducted a study on the development of remote diagnostics services with embedded digital technology in a fleet of public transport (buses). With remote diagnostics services, signals regarding different bus parts are transmitted wirelessly to a back office where they are further analyzed by some experts with a pattern seeking algorithm. With this technology, any deviation from the regular patterns can be identified. In this way, faults in bus parts can be predicted before any breakdown occurs. This enables various digital

services such as fault prediction, proper error reporting, maintenance scheduling etc.

Previous studies on the architecture of vehicular remote diagnostics merely have discussed the architecture of the remote diagnostics software modules. The studies do not discuss the other important functional elements, such as devices, network, contents, and hence they do not explain how the arrangement of different functional elements can deliver the remote diagnostics services. Unfortunately, a holistic picture of the architectural characteristics of the remote diagnostics services is missing.

Previous Information Systems (IS) studies on remote diagnostics of industrial equipment discuss remote diagnostics from the perspectives of IT infrastructure and ubiquitous digital platforms. These studies discuss the infrastructure of remote diagnostics, i.e., different elements of remote diagnostics and how the infrastructure enables the remote diagnostics services. However, an explanation is missing concerning the arrangement of the functional elements that provide remote diagnostics services. It is important because it can give us a picture of how remote diagnostics services are architected. Without knowing about the underlying architectural characteristics of the remote diagnostics services, it can be difficult to understand the implications of the digitalization of vehicles using remote diagnostics.

We applied the concept of the layered architecture of digital technology by Yoo et al. [8] to understand the architectural characteristics of the digital services. One contribution of this paper is to describe the architectural characteristics of the digital services enabled by embedded technology, as little is known about their characteristics. This contributes to the literature on innovation in the digital age [5, 8, 9, 10, 11, 12]. As not much empirical studies have been conducted on the layered architecture of digital technology, another contribution of the paper is that we have empirically applied the framework of layered architecture to enhance our understanding of the architectural characteristics of embedded technology enabled digital services.

## 2. Remote diagnostics

Research on remote diagnostics is an expanding field of inquiry. Research in this area has mainly developed along three perspectives: 1) the IT infrastructure perspective, 2) the ubiquitous computing platform or digital platform perspective as it is phrased in the IS literature, and 3) the software architecture perspective of the remote diagnostics technology, which is mainly researched in areas outside IS.

Remote diagnostics of vehicles implies several functional requirements: (i) Multi-Sensor integrated monitoring and control Systems; (ii) Communication and integration of geographically dispersed machines through a multimedia information environment; (iii) Data abstraction – only the relevant data is to be transmitted through the network; (iv) Knowledge acquisition and learning; (v) Tele-Maintenance and collaborative diagnostics to facilitate the technical personnel to perform diagnostics on machines that are geographically distributed [13, 14, 15].

Based on the installation of various embedded devices, remote diagnostics systems can collect data on the vibrations of bearings, temperature, pressure and speed of industrial equipment. Monitoring of such important data makes it possible to find problems in the equipment well in advance. Thus, remote diagnostics reduces the risk of machinery breakdowns. As sensors are embedded in the equipment, it becomes possible to go beyond object identification and measure their status or condition [16, 17]. When different parameters are measured, remote diagnostics systems have the capability to notify a problem before it occurs.

In this way, the remote diagnostics is oriented towards a long-term focus [16]. Various kinds of knowledge-intensive value-adding services (such as learning from failures through rule-based decision-making, statistical sampling and data mining) can be provided by remote diagnostics [18, 19]. In this way, remote diagnostics ensures uptime improvement of the equipment that it monitors and thus it creates an opportunity for ubiquitous computing [20]. Many industrial organizations are implementing remote diagnostics systems as the cost of sensors has decreased, their networking capability and environmental adaptability have increased and they can be used as ubiquitous platform for inter-organizational communication [16].

The software architecture of remote vehicle diagnostics has previously been studied [21, 22]. The studies focused on the software modules of remote diagnostics and there is a lack of a holistic picture regarding the architecture of remote diagnostics with hardware, network, application program and contents. The understanding is required because remote diagnostics services do not just include software or hardware. Just like any other digital services, they also follow layered architecture with four layers: device layer, network layer, application program layer and contents layer [8].

## 3. Digital service architecture

### 3.1 Layered architecture

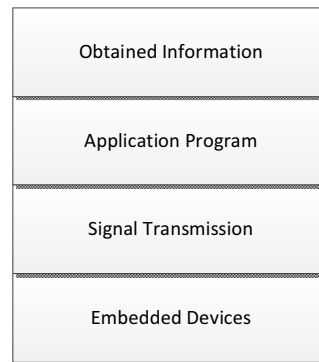
The layered architecture of digital technology consists of the following layers: the device layer which deals with hardware and operating systems, network layer which manages logical transmission and physical transportations (cables), service or application program layer which provides application functionality that directly serves users during storage, manipulation, creation and consumption of contents., and content layer which contains data such as texts, images, sounds, video etc [8].

Because of the continuous digitalization of earlier non-digital products and services, this four-layered architecture of digital technology has become more expansively applicable for all types of digitalized products. Before digitalization, these four layers were tightly coupled together with a particular product boundary and in the case of purely mechanical products, such as an automotive, these layers did not exist at all. As a consequence of the digitalization, these four layers will be decoupled or loosely coupled to a greater extent [8]. It creates the opportunity to combine components from different layers using sets of protocols that can create alternative digital products. This is known as combinatorial innovation [23].

### 3.2. Layered architecture of the remote diagnostics services

In the case of remote diagnostics (Fig 1), the device layer generally consists of embedded devices [24]. Devices are embedded in different parts of a machine, e.g., a vehicle. Every embedded device is normally designed to perform a specific task. For example, a sensor embedded in a vehicle to check the intake air temperature only performs that specific task [25]. In remote diagnostics, due to the embedded nature of a device with a particular part in a machine, often a device functions for a particular part. At the network layer of remote diagnostics, there exist two parts: i) wired signal transmission within an internal network in a vehicle or other industrial machine and ii) wireless signal transmission to a remote service station [24]. Wired signal transmission makes the network to some extent follow a single design hierarchy, i.e., the internal network in a machine is designed to function only within the machine. The next layer of the remote diagnostics consists of application program. The application program can be used for the diagnostics operations within an industrial machine such as crane or vehicles and also for analyzing the signals remotely at a back office [16, 26]. The application program can be used to analyze different sensor signals, identify various patterns and thus can work as an intelligent analytical tool for various fault predictions and diagnosis [22]. Thus, it is open for conducting different

kinds of analyses and remains fluid in meaning. It is unlike the embedded devices that provide just fixed values. The application program is not product specific, but rather product agnostic, as it can be used with the machines for on-board diagnostics as well as remotely at a back office computer [22]. The design and use of the application program thus follow a multiple design hierarchy as it can be used in different ways. Information obtained through the application program is also product agnostic. The information can be sent back to the machine so that the machine operator (e.g., a bus driver) can understand it in the form of some graphical information about the health status of a machine part. The information can also be sent to the maintenance management personnel when the analysis predicts some faults so that the management knows which part/parts to be repaired in the coming days [22]. Thus, the information can be reprogrammed to be used in different ways. Figure1 shows the layered architecture of the remote diagnostics services.



**Figure1. Layered architecture of Remote Diagnostics Services (Adapted from Yoo et al. [8])**

### 3.3. Layered modular architecture continuum

Due to the continuous digitalization of physical products, a new architecture emerges [8, 27]. This new architecture is layered modular architecture which is a hybrid between a modular architecture and a layered architecture. Yoo et al. [8] present a continuum where one end of the continuum shows modular architecture that is applicable for traditional industrial-age, single purpose products, and the other end represents the layered modular architecture that is applicable for the conventional digital products with general computer hardware.

The architecture continuum shows three unique characteristics of digital technology: (1) re-programmability, (2) homogenization of data, and (3) self-referential nature of digital technology [8]. The re-

programmability allows a digital device to perform a wide array of functions such as, calculating distances, word processing, video editing and web browsing. Homogenization of data refers to the fact that any digital content such as audio, video, text and image can be stored, transmitted, processed and displayed using the same digital devices and networks. For example, an iPhone is not only a phone, but also a camera, a music player, a video player and so on. Self-reference means that digital innovation requires the use of digital technology, e.g., computers. The architecture continuum shows that presence of these three characteristics is low in the case of the modular architecture and high in the case of the layered modular architecture. It means that these three characteristics are the driving forces of digital innovation.

Although loose coupling between components through standardized interfaces exists in both types of architectures, substantial differences also exist between modular and layered modular architecture. Modular architecture has fixed product boundary and meaning. It has product specific components which implies that the use of a product with modular architecture is fixed and single purpose. On the other hand, layered modular architecture has fluid product boundary and meaning and also has product agnostic components. This means that as a result of digital innovation of a previously non-digital product or service, the resultant digital product/service can be used in different ways. Yoo et al. [8] discuss Google Maps as a prime example of digital innovation which can be used as a standalone product as well as in different ways with the help of heterogeneous devices like cars, digital cameras, mobile phones etc.

The services enabled by digitalization of vehicles are influenced by the vehicle itself, the digital devices, application functionality and the communication channels etc. Thus, it can be argued that the architecture of such digital services can exhibit modularity and some aspects of layered modularity at the same time.

#### **4. Research setting and approach**

This research reports from a collaborative project between a bus manufacturing company SmartBus (pseudonym) and a group of researchers from a university in Northern Europe. The engineers and service business developers from the SmartBus, computer scientists and information systems researchers from the university were involved in this project. Two of the authors of this paper are among the information systems researchers. SmartBus is one of the largest bus manufacturers in the world. Besides

selling buses, they also provide maintenance services for the buses once they are sold. SmartBus is very well known for bringing innovative technology in the bus manufacturing and maintenance services. One such innovation is the introduction of remote diagnostics services (RDS) for their buses. Modern buses have embedded sensors and Electronic Control Units (ECU) in various parts. At present, the ECUs collect signals from the embedded sensors and send error notifications to the dashboard with the help of a communication channel inside a bus called Controller Area Network (CAN). An error notification takes place when something is already wrong with a bus part. Remote diagnostics services are different. RDS aim to predict faults in advance. In this project on RDS, SmartBus and the researchers develop an embedded device in each bus called VACT to collect signals from the ECUs with the help of the controller area network (CAN). A VACT collects signals, processes them and transmits them wirelessly to a remote station. In the remote station, using a pattern seeking algorithm, a group of experts can analyze different signals coming from a fleet of buses so that they can identify the deviation pattern among different parts in the buses in the fleet, diagnose and predict a fault. This reduces the risk of breakdowns as faults are predicted in advance. With the introduction of new embedded technology inside the bus, the architectural characteristics of the maintenance services change. Previously, the information regarding error in vehicle parts was only available inside the bus. Remote diagnostics services introduce a new signal processing device, wireless transmission and analysis at a remote station. The whole scenario of maintenance service provision changes due to this digitalization. Because of the introduction of new device and network capability in remote diagnostics services, it is evident that the architecture of the maintenance services changes and remote diagnostics services possess different architectural characteristics. However, it is not clear what the characteristics are. This research aims at understanding the architectural characteristics that are formed due to the digitalization.

A qualitative study has been conducted for this research. Qualitative studies help to understand and explore new technology [28]. Qualitative studies aim at understanding the phenomenon from the points of view of the participants [28, 29], and the rationale behind choosing qualitative study in this research is to i) understand a new technological phenomenon in the form of remote diagnostics services and ii) to get the points of view of the engineers and computer scientists who are behind the development of the remote diagnostics. Qualitative studies are useful to understand a context within which the participants act

and influence the context [30]. In this research, the points of view of the engineers and the computer scientists are important as they are the most influential people in the development of the remote diagnostics.

#### 4.1. Data collection

Data has been collected from several sources. The data sources consist of i) project meetings, interviews, project documents that explain different aspects of the project, ii) technical reports that the engineers prepared during the project, iii) email correspondences between project members during the project, and iv) weekly reports prepared by the project manager based on the different weekly activities in the project.

There were two kinds of project meetings: monthly project meetings and project meetings on demand. In the monthly project meetings, project members met to describe their latest findings and discuss several issues raised by different project members. There were in total 20 monthly project meetings. Two of the authors of this paper took part in the meetings as project members. The engineers of SmartBus and the computer scientists from the university showed several important technical aspects on remote diagnostics services and explained them. Two of the authors of this paper took notes during the meetings and also ask questions that were related to technical features of remote diagnostics services. It helped the authors to collect data regarding the architectural characteristics of the remote diagnostics services. There were 30 additional meetings organized by different project members to discuss the development of the remote diagnostics services. In these meetings, the project members mainly discussed the business aspects of the remote diagnostics. Some important features of the architecture of remote diagnostics services were noted during these meetings.

Moreover, 4 engineers from SmartBus and 3 computer scientists from the university who were involved in this project were interviewed. Based on the layered architecture of the remote diagnostics services, questions were asked about the embedded devices, signal transmission, application functionalities and the rendered information from the application. All the interviews were transcribed.

The project documents, technical reports, email correspondences between the members are also collected for analysis.

#### 4.2. Data analysis strategy

Our data analysis involved three steps: data reduction, data display and conclusion drawing [31]. In the data reduction step, we selected the empirical

materials that describe different technological aspects on remote diagnostics services. For example, we searched for data that explains characteristics of embedded sensors, ECUs, VACT, transmission channels, pattern seeking algorithm. Interview quotes, meeting notes, excerpts from project documents, emails that do not focus on the technological aspects were set aside. In the data display section, we organized the data using the layered architecture of remote diagnostics services. This helped us to categorize data regarding embedded devices, signal transmission, application functionalities and rendered information. For example, the empirical materials that describe characteristics of different embedded devices were set as one category. Relevant empirical materials were also categorized for signal transmission, application functionalities and rendered information.

**Table 1. Categories for Data Display**

Category for data display	Identification from the data
Embedded Devices	Data that describes features of embedded sensors, ECUs in various bus parts and other embedded device VACT
Signal Transmission	Data that describes different features of Controller Area Network (CAN) and wireless transmission
Application Functionalities	Data that describes about the pattern seeking algorithm
Rendered Information	Data that discusses the information obtained after analysis by the algorithm

As conclusion drawing is interwoven with data reduction and data display [31], before drawing any conclusion, the authors constantly discuss together during the data reduction and display activities. The development of this intersubjective consensus helps for validity of the analysis [31].

### 5. Findings

SmartBus's (Pseudonym) Remote diagnostics services (RDS) consist of some essential parts: the embedded sensors with the bus parts, the embedded signal processing device (VACT) in every bus, the pattern seeking algorithm COSMO and information obtained from the analysis by the algorithm. To

understand the architecture of remote diagnostics services, it is required to understand each of them as the architecture of the RDS consists of all the parts. The next sections delineate findings after analyzing the collected data.

### 5.1. The embedded sensors in the bus parts

In Remote Diagnostics Services (RDS), the initial information is obtained from the sensors embedded in the bus parts. In this section of our findings, first we are going to explain how sensors generally work. The findings about the sensors provide a general understanding of the architectural characteristics of the sensors. Every modern bus consists of numerous sensors embedded in different parts. Every embedded sensor performs a specific task. For example, a wheel speed sensor is used to read the speed of a bus's wheel rotation. Similarly, some other parts of a bus also have embedded sensors to perform specific tasks. The information obtained from a sensor has fixed meaning, e.g., a sensor is normally fixed for a bus part and thus each sensor generally performs a fixed operation for a particular bus part.

Sensors are constantly collecting data from different parts of a bus. Every sensor is connected to a bus part through standardized interfaces. If there is any problem with any sensor, it can be replaced. The sensors are connected to the Electronic control units (ECUs). ECUs collect signals from the sensors and control the operations of various important parts of a bus. A sensor embedded in a bus part is a low level device that is hard to be re-programmed and in most cases it is not re-programmed. That is because the number of embedded sensors is large and each sensor is supposed to perform specific tasks with a particular part of a bus.

Thus, the initial sensor data works as the input for the remote diagnostics services for the advanced analysis. In this way, sensor data provides the foundation for the remote diagnostics services.

The architecture of the sensors is often designed by the bus manufacturing company itself. To design a sensor for a bus part, it is very much required for a company to have the knowledge of the bus parts.

The architectural characteristics of the embedded sensors have similarities with the modular architectural as the sensors have low re-programmability, fixed functionalities, perform operations for specific parts. Moreover, to design the sensors for buses it requires product (bus) specific knowledge.

### 5.2. VACT in each bus

In SmartBus's Remote Diagnostics Services, a very important device is VACT. VACT is a digital device

that is embedded in each bus and connected to the ECUs to perform some tasks. According to an engineer:

*The VACT collects signals from the ECUs, processes the signals and transmits the signals to a service station with the help of wireless transmission.*

As mentioned earlier, ECUs collect signals from the sensors. The importance of VACT in the remote diagnostics services becomes clear from the following comment from a computer scientist who was involved in the project:

*Sensors cannot do onboard diagnostics. Instead of some experts dealing with the signals from the sensors once the problem occurs, the essential thing is to do onboard diagnostics of the signals and send the information remotely to a service station so that the service station staff can see what's going on with the bus. VACT is particularly designed to do the onboard diagnostics.*

In other words, VACT is basically processing all the sensor data and this processing yields diagnostics information that can be helpful to predict any anomaly that occurs in a vehicle part to reduce the risk of a breakdown. Every VACT is specific to a bus. So, a VACT cannot collect data for several buses. Just like a sensor typically is concerned with a bus part, a VACT is concerned with all the sensor data within one bus.

However, as mentioned earlier, VACT can perform several tasks: collecting data, processing and transmitting the data. So, from that point of view VACT is not a fixed purpose device. New software can easily be uploaded to a VACT to perform new functions. A technology developer explained:

*Yes, the VACT is re-programmable. We can upload new software to it. We can even do it wirelessly to VACT and run the new software instead of what it is running now. This new software can then include new functions.*

The importance of VACT being re-programmable is enormous for remote diagnostics services. Various diagnostics operations can be performed with the help of the VACT. If the experts realize that the VACT should perform more functions than what it is doing right now, new algorithm can be developed to perform more functions for the diagnostics of the bus parts based on the sensor data. In this way, it creates an opportunity to get precise diagnostics information which is not possible without VACT.

VACT can be explained with its own four layers like any other digital technology. VACT has a device layer that consists of different hardware units. Its network layer deals with the transmission of signals from the sensors to the remote station. It is operated by an application program called COSMO (to be explained later) and it delivers contents in the form of

processed signals. Thus, within the layers of the digital services, VACT operates with its own four layers.

Due to the dependence on the signals received from the sensors, every VACT has its limitations. Although it can perform various processing, its functionalities cannot go beyond processing the signals received from the sensors. Every VACT system is affected by the limitations of the sensors. If any sensor does not function properly, the application functionalities within the VACT will eventually struggle to provide accurate information.

Thus, within the device layer of Remote diagnostics services, we can see the existence of a device that is re-programmable. Unlike the sensors that can be difficult to re-program, VACT is re-programmable. In this way, VACT has the following architectural characteristics: re-programmable to a large extent, perform multiple operations, consists of four layers. These characteristics make VACT less modular in nature rather than more layered modular.

### **5.3. Controller area network (CAN) and wireless transmission**

During the discussions with the technology developers, we have found how the networking is done for remote diagnostics. Every ECU is connected in parallel to Controller Area Network (CAN). A CAN is a networking system inside a bus. Due to the complex nature and cost for point-to-point connections between the ECUs, the CAN has been used for the vehicular networking purposes. This makes the communication between the ECUs much easier and faster. A bus has more than one CAN system. The ECUs are connected to a CAN through the nodes. In this case of remote diagnostics, the VACT is also connected to two of the CAN systems inside a bus via nodes. CAN is designed specifically for inter vehicular data transmission. Thus, it is very much product (vehicle) specific. It is designed to perform data transmission activities inside a vehicle, e.g., a bus.

In our case, the processed signals by the VACT are wirelessly transmitted to a back office with the help of GPRS technology. The technology developers write server programs so that the VACT can communicate with the servers at the back office.

Here we also observe the existence of the characteristics of both modular and layered modular architecture at the same layer, i.e., the signal transmission or the network layer. CAN is very product specific and lowly re-programmable. On the other hand, GPRS is re-programmable to a great extent and not product specific.

### **5.4. Pattern seeking algorithm ‘COSMO’ and the information obtained after the analysis by COSMO**

Another important part of RDS is the algorithm that seeks deviation patterns among the fleet of buses from the information gathered from the embedded VACTs in all the buses. As mentioned earlier, a VACT in a bus can provide information about one bus. The information from all the VACTs in a fleet of buses are transmitted remotely to a service station and then analyzed with a pattern seeking algorithm named COSMO. The information collected from the VACTs is analyzed with COSMO to seek deviating patterns among the buses in a fleet. When a bus within a fleet deviates from the other buses, the data obtained from that bus is checked to predict the fault. An engineer explained the usefulness of COSMO and the motivation behind using it:

*We are interested to know about the common problem or problems that occur within a fleet of bus. We are working with nineteen buses. If one particular problem occurs with a particular part in several buses, we can come to a decision that a specific part in the buses is faulty and required to be built or designed differently to reduce the problem in future. Finding a unique problem with just one bus cannot help to come to that conclusion.*

Unlike sensors and VACT that only work within the buses, COSMO is a very advanced algorithm that is used by the experts in a service station. From that point of view, it is not fixed to function within a bus. It works with all the data collected from a fleet of buses. Different analyses are constantly done on the data received from the buses to identify various deviating pattern within the fleet. These analyses provide new meaning to the existing data.

There is a co-creation aspect of this algorithm. The engineers asked the drivers and traffic managers in a bus operating company about regular problems with bus operation and maintenance. Moreover, the engineers of SmartBus and the computer scientists from the university used the existing service records of the transport operating company to use them with the algorithm. Service records keep track of all previous maintenance and repair history. The use of COSMO with the service records helps to understand breakdown pattern of a particular bus or bus parts. This, in turn, helps to decide about the problems regarding a bus or a bus part.

COSMO is product agnostic. Although it is used at the back office computers, a part of the COSMO algorithm must be used with each VACT inside the buses. Without that part of COSMO, VACT cannot perform on-board diagnostics. Thus, the algorithm in

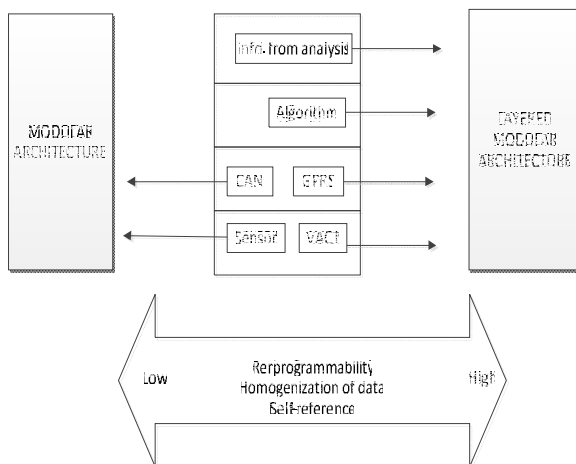
VACT operates within a bus. With COSMO, it is not the issue with where to use the algorithm; the issue is how to use it. Numerous operations on the existing data can yield different interesting patterns in the information obtained from all the VACTs in the buses. These operations are not possible with just one VACT.

COSMO depends on the information obtained from the VACTs, which in turn means that the limitations that exist with the VACTs thus also exist with COSMO.

The COSMO algorithm is a patented algorithm. SmartBus is not going to allow other companies to work with this algorithm. This makes it a closed system and hence innovation can only take place within SmartBus as other companies cannot innovate upon it. This creates a hindrance on other companies to create new functions and services.

From our findings, we can say that COSMO is following many characteristics of layered modular architecture as it is highly reprogrammable, product agnostics, can perform multiple analyses.

Information obtained from COSMO analysis can also be re-programmed. It can be sent back to buses so that bus drivers are informed of any anomaly. It can also be designed to develop an app for smartphones. Thus it becomes product agnostics, i.e., can be used with heterogeneous devices. Thus, the architecture of the information layer inclines towards layered modular architecture. The following figure 2 shows the architectural characteristics of remote diagnostics services. The thin arrows show the inclination of each layer towards a particular architecture.



**Figure 2. Presenting the findings based on the Layered Modular Architecture continuum by Yoo et al. [8]**

## 6. Discussion

In this paper, we investigate the architectural characteristics of digital services enabled by embedded technology. Based on our empirical study on remote diagnostics services (RDS), we are now going to discuss the characteristics.

### The architecture of the digital services spans along the layered modular architecture continuum

Our findings show that the embedded devices and the networking systems in the remote diagnostics services follow characteristics of both modular and layered modular architecture. Although digitalization moves a product with modular architecture towards layered modular architecture [8], our findings show that both architectural characteristics co-exist at the device and network layers after digitalization.

The embedded nature of the sensors with a modular physical product (the bus) enforces the devices to follow the modular architecture. However, as we have found in our study, there are embedded devices such as VACT that does not totally follow the characteristics of the modular architecture. It has features of layered modular architecture. Thus the devices span along the continuum.

At the transmission layer, the wired network inside the bus also makes the network layer to some extent follow the modular architecture. High dependence on wired network within a physical product puts the characteristics of the network layer close to the modular architecture. On the other hand, there is network capability such as GPRS that does not follow the modular architecture characteristics as it can have medium to high re-programmability. Thus, characteristics from both modular and layered modular architecture co-exist at the signal transmission layer of the remote diagnostics services. The characteristics also span along at that layer.

### The application program of the digital services is simultaneously de-coupled and partly coupled with the embedded devices

Previous studies show that digitalization makes the application program and device layers de-coupled or loosely coupled [8, 11, 27]. Our findings show a new characteristic. The findings show that the application program can be at the same time de-coupled and partly coupled with the embedded devices. The COSMO algorithm is used at the back office after receiving all the data from the VACTs. The analysis can be done without having any link with any VACT. That makes COSMO de-coupled from the VACTs in the buses.



However, a part of the COSMO algorithm is continuously used with each VACT which is embedded in every bus. This makes COSMO partly coupled with the VACT and at the same time de-coupled from the VACT. When digital services are enabled by embedded technology, a coupling of application program with embedded devices is required. This is evident from our findings.

#### **There are layers within layer of the digital services**

Yoo et al [8] explain four layers of digital services. Our findings add to the discussion by showing layers within layer. The embedded device (VACT) in RDS has its own four layers: the device layer, network layer, application functionalities layer and the content layers. This implies that although an embedded device itself operates in the device layer of the digital services enabled by embedded technology, it has its own operations within its own four layers. This particular characteristic of layers within layer influences the overall digital service architecture and it shows a distinguishing aspect of embedded technology enabled digital services. In our case, the four layers of VACT work together with the other embedded sensors and existing GPRS technology and influence the whole provision of the digital services. Every VACT's own application program layer performs specific on-board diagnostics operations and then transmits the diagnosed signals to the back-office for further analysis for pattern seeking. If its four layers cannot operate properly within the device layer of RDS, there will be negative effect on the vehicular remote diagnostics services.

#### **The application program layer of the digital services is a closed innovation platform**

Due to the loose coupling between the layers in a layered architecture, innovations can be executed at any layer by firms by sharing standards and protocols [8, 11, 12]. Although the application program layer of the remote diagnostics services follows many characteristics of layered modular architecture, such as product agnostics nature or fluid meaning, our findings show that the standards and protocols are not shared among firms. Due to the patented algorithm, innovations cannot be done by other companies. This particular architectural characteristic of remote diagnostics services creates a scenario of closed innovation where only the vehicle manufacturing company can innovate upon the algorithm. This implies that in case of embedded technology enabled digital services, creating application program with closed system can shut the door for open innovation.

## **7. Conclusion**

In this paper, we have investigated the architectural characteristics of the digital services enabled by embedded technology. We have studied the vehicular remote diagnostics services and identified some characteristics that are distinctive from the regular views about digitalization. Four characteristics have been identified: i) digital services span along the continuum of the layered modular architecture, ii) the application program of the digital services are simultaneously de-coupled and partly coupled with the embedded device, iii) there are layers within layer, i.e., embedded digital device of the device layer of digital services has its own four layers, and iv) the application program layer is a closed innovation platform. This research contributes to the ongoing discussion on digital innovation [5, 8, 9, 10, 11, 12]. By applying the framework of layered architecture by Yoo et al [8], we have contributed to the discussion on the effect of digital innovation of previously non-digital physical products. This particular research sheds light on digital innovation with embedded technology. Digital innovation can take place in different ways and innovation with embedded digital technology in non-digital physical products is one such example [8, 27]. We exhibit a case of vehicular remote diagnostics services that explains digital services enabled by embedded technology in vehicles. These kinds of digital services got attention in information systems (IS) literature and discussed from an IT infrastructure and ubiquitous computing perspective [18, 20]. However, previous IS research did not discuss about the architecture of these digital services. The existing research on the architecture of embedded technology enabled digital services did not provide a holistic picture. Thus, this paper makes a contribution to IS by explaining the architectural characteristics of the digital services in the form of remote diagnostics services. This research also shows some practical challenges. Due to the existence of modular architecture, sometimes digitalization becomes difficult. Dependence on the components with modular architecture creates a hindrance to digitalization.

## 8. References

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