# Service-Oriented Integrated Information Framework for Next Generation Intelligent Construction Supply Chain Management

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**Abstract**

It is essential to perform an effective construction supply chain management in large-scale building construction projects. Since 2006, this research consortium has conducted a research project, named Next generation Intelligent Construction Supply chain management (NICS), that develops a process and a system that support an proactive construction supply chain management in real time by taking advantage of ubiquitous sensor network(USN) and radio frequency identification (RFID) technologies. In this project, 'next generation' means using USN/RFID technology to improve the current process of construction supply chain management, while 'intelligent' means that equipments, such as pallet, trailer, hoist, and gate, can recognize components or material that they carry or hold and communicate the information with other equipments or actors involved by using USN/RFID. This paper focuses on building an information framework that can support real time information sharing and exchange among different legacy systems operated by general contractors and suppliers as well as among equipments and actors involved. Without the information framework, information related to construction supply chain cannot be managed effectively and efficiently in the NICS environment. In the logistics industry, many researchers proposed that loosely coupled system architecture on the basis of service oriented architecture (SOA) could be a solution with providing expandability and flexibility in exchanging and sharing information among heterogeneous and geographically dispersed information systems. Based on the idea on SOA, the objective of this paper is to develop an integrated information framework and a system to support the NICS environment, where USN/RFID technologies are used, by utilizing the SOA concept. Additionally this paper describe the identification of services and information model for developing SOA based NICS environment, and include the introduction of being developed a prototype system as well.

***Keywords:*** Information Management, SOA (Service-Oriented Architecture), Supply Chain Management, Logistics, Information Technology, Construction Management

## Introduction

With the current construction industry practices aiming at building larger, super-tall structures, many new approaches are being made to ensure effective construction management, including applications of new management techniques and incorporations of IT technologies. Efficient logistics management in the construction of mega-tall buildings, in particular, is considered an essential factor that leads to a successful project. Recognizing the importance of such, wide spectrums of studies have been conducted on automated logistics management that involves the shift in paradigms in logistics management (e.g., JIT, SCM) and the use of cutting-edge IT technologies such as bar cords and RFID (Chin et al. 2005;Jaselskis 2003). Recently, logistics management in the construction industry is leaving the past's site-based delivery and release management approach for a more comprehensive system that takes care of the entire supply chain, covering orders of building materials, production, release, delivery, hoisting/heavy equipment handling, placement and installation. The expansion of the management scope is requiring all project participants, including suppliers, to adopt a new environment where all players share and co-manage necessary information on a real-time basis to guarantee successful operations. This is seen as a departure from the conventional information-processing systems that are site-or contractor-centered in nature (Chin et al. 2008). Despite the state-of-the-art technologies being adopted, the supply chain-based information management approach relies heavily on manual work, which leads to the omission or fallacy of information that contributes to the breakage in the information flow or damage to reliability due to errors in information. Other problems with the supply chain management based on the use of bar cords, RFID and other IT gadgets include difficulties in collecting and utilizing relevant information because of: (a) differences in the level of informatization by the contractor(s), the sub-contractors and the suppliers; and (b) their lack of clear understanding of the information systems or inexperience with handling such systems.

IT technologies are steadily evolving and making progress, offering varieties of techniques and possibilities. Ubiquitous sensor network (USN), in particular, is being brought closer to users, thereby suggesting various opportunities in the collection and management of information in the construction industry.

Since 2006, this research consortium has conducted a research project, named Next generation Intelligent Construction Supply chain management (NICS), that develops a process and a system that support an proactive construction supply chain management in real time by taking advantage of ubiquitous sensor network(USN) and radio frequency identification (RFID) technologies. The aim of the project is to solve problems associated with evolution of the technologies, errors made in collecting information, differences in the level of informatization shown by project-participating parties, and additional work that may become necessary to complete gathering of information. In this project, 'next generation' means using USN/RFID technology to improve the current process of construction supply chain management, while 'intelligent' means that equipments, such as pallet, trailer, hoist, and gate, can recognize components or material that they carry or hold and communicate the information with other equipments or actors involved by using USN/RFID. In other words, the NICS project is an initiative to establish an intelligent construction supply chain management (CSCM) environment where equipment, which used to be regarded as a mere vehicle to transport materials from places to places on the CSCM process, is endowed with intelligence so that they can recognize material information and can transmit and share information with other equipment via wireless networks. For instance, when a construction material such as plaster boards is manufactured at a factory and boxed, with an RFID tag attached to the box, the intelligent pallet is fed with the name of the material to allow for the release of the item. Then, the pallet reads the RFID tag and automatically recognizes the information. To release the materials whose information is loaded in the pallet, an approach is made to the intelligent trailer. Next, the Zigbee communication enables the recognition of the materials that have been loaded onto transportation for carriage and verifies whether or not correct items have been loaded for transport. Additionally, when the intelligent trailer approaches the GateSensor, the device will determine whether or not the planned materials are being released as scheduled.

As mentioned above, the present authors are developing wide varieties of supporting equipment, e.g., intelligent pallet, intelligent trailer, GateSensor (Lee et al. 2008), and intelligent hoist, as well as the systems that will effectively accommodate the automated CSCM environment. To ensure the establishment of the environment, a number of activities are being required, including the development of equipment and systems and various interfaces between equipment, between equipment and servers, or between servers and the existing legacy system. Considering in particular the industry-specific characteristics of substantial non-formality, the information management systems or solutions are called for that will be able to effectively support integration within each project or between multi-stakeholders.

Therefore, the present authors proposed a service-based integrated information framework whose features have been described earlier, and accordingly conducted processes to verify the efficacy of the framework by materializing a prototype system.

## Research Methodology

The service-based integrated information framework proposed in this study refers to a comprehensive information management system wherein the information produced in stages prior to construction logistics management is efficiently collected and shared by stakeholders, as intelligent equipment are operated in a CSCM environment which adopts ubiquitous technologies such as RFID/USN. The system in question must show quick adaptability to changes in the non-formulated processes and be able to offer an integrated management environment which is based on the sharing of information via communication between various equipment items and the building of efficient interfaces with the existing legacy system.

As reviewed above, it is surely a challenge to design an information management system by effectively combining the complicated, heterogeneous and geographically dispersed environments. One solution to such task is the service-oriented architecture (SOA) concept, and a number of studies have proven that it offers an optimal approach to build an integrated management system in the logistics industry. Therefore, the present authors came up with the following processes to help develop a framework to be used in establishing a loosely-coupled integrated management environment required in NICS:

To gather and review the existing literature and case studies on SOA, based on previous NICS environment analyses;

To analyze NICS environment, by using SOA-suggested methodology(s);

To propose an SOA-based NICS management environment;

To organize services that are needed for system operations and to design a system based on the serviced identified; and

To verify the efficacy of the SOA-based integrated information framework, by materializing the prototype system.

## NICS Environment

As described earlier, NICS offers a vision for the future CSCM environment and offers the establishment of automated CSCM systems centering around, as illustrated in Figure 1, RFID, USN (e.g., Zigbee, Wibro, CDMA, Wi-Fi), mobile (e.g., PDA, UMPC), and intelligent pallets and trailers, GateSensor, and intelligent hoists that show combinations of various IT equipment. At the present, equipment development for the prototype and inter-equipment communication testing are all completed.

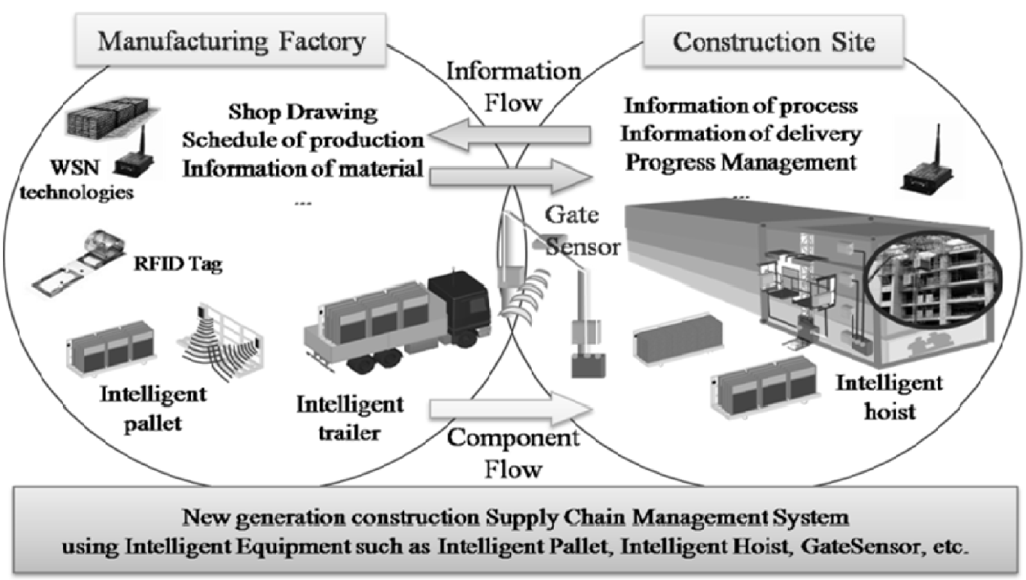


Figure 1. The vision of Construction Supply Chain Management of next generation (Lee et al. 2008)

Figure 2 below is an UML sequence diagram designed to illustrate communication between some of the intelligent equipment items, i.e., intelligent pallets and intelligent trailers.

Reviewing the diagram primarily for major information flows, the following processes are present: (1) materials are loaded onto the intelligent pallet (1.Load MaterialSet); (2) the lode cell begins to operate

(3.Recognize loaded weight); (3) this wakes up the RFID tag reader, Zigbee, and UMPC; (4) the RFID tag ID (8.Read RFID tag) recognized by the RFID tag reader is stored in the Zigbee memory (10. Write RFIDID in Zigbee memory); (5) the RFID tag ID is transmitted to UMPC's RFID tag ID via the RS232C serial communication (11. transfer RFID tag ID by RS232C); (6) the transmitted RFID tag ID works to initiate a log-in to the logistics server to pull out detailed materials information and bring it onto a display on the screen; and (7) when an intelligent pallet approaches an intelligent trailer, a Zigbee connection (17.connect Zigbee) is made, having the intelligent pallet's Zigbee memory-stored RFID tag information sent out to the intelligent trailer's Zigbee, thereby enabling an inter-equipment communication. As illustrated in the aforementioned information flow, lack of a cohesive and integrated information management system between a number of communication-supporting and display device modules and multi-servers will likely cause grave difficulties in maintaining consistency in the information. Not having a loosely-coupled interface-based system will also likely compromise the environment's quick and flexible response to changes in the modules and communication methods that comprise parts of intelligent equipment when such changes are called for. If the interface design is not a standardized one, time and cost issues will inevitably arise with each ensuing integration mission.

To help solve the problems described above, it appears necessary to build an SOA-based integrated information framework. It should be the one based on interfaces that: (a) allow for the establishment of integrated systems which efficiently accommodate heterogeneous and geographically dispersed environments; and (b) are certified as an international standard.

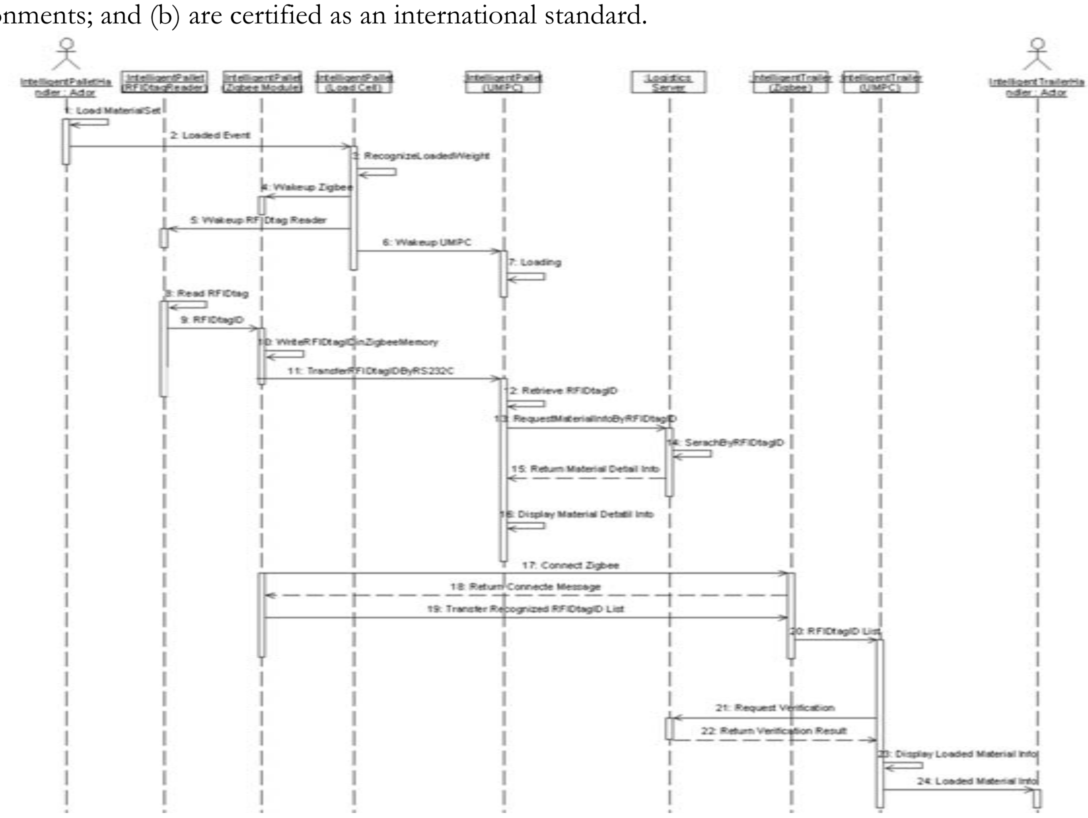


Figure 2. Communication between Intelligent Pallet and Intelligent Trailer

## Review of SOA for building NICS environment

Ever since the Gartner Inc. published SOA in April 1996 as the standard interface method, SOA has been defined as a comprehensive set of IT strategies that include: (a) architecture development involving the building of web services as well as the entire application as a service unit; (b) policies to help materialize SOA; and (c) rules and shared service management. In fact, the basic concept of SOA was already being used in distribution techniques such as common object request broker architecture (CORBA) and distributed component object model (DCOM), though technical inexperience and the lack of exposure standards and cooperation between major software vendors have brought little attention to it. But with an arrival of the XML-based web services, SOA is stepping into a new limelight.

Figure 3 below shows the conceptual model of an SOA architectural style indicated in UML writing. The diagram consists of **Service Consumer**, **Service Provider**, and **Service Broker**, featuring a structure wherein **Service Description**, a standardized invoice, is used to have services that the **Service Provider** offer delivered to the **Service Consumer** by the **Service Broker** (Wikipedia 2008).

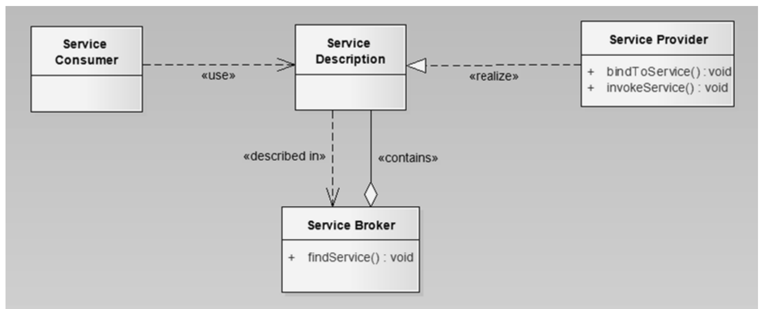


Figure 3. Conceptual model of a SOA architectural style

The biggest benefit of SOA is its ability to expose re-usable functions to the outside by complying with the standardized interface regulations/requirements and to render the functions re-usable via only service binding. The strategies also allows for the concept of software as a service, where a software program acts as a service, offering relevant functions. Recently, SOA is being applied as an architecture to help ensure integration into a legacy system, in particular to establish interface between devices or an integrated environment under heterogeneous and geographically dispersed information systems. Studies on the logistic industry have proven that effective interface between various channels on the supply chain with complicated structures is leading to fast and flexible responses to the changes in the process. Based on the findings, wide varieties of trials are being made to help coordinate and integrate complex systems during the construction of a u-City that depends on ubiquitous technologies. The NICS environment mentioned earlier is composed of multi-faceted dispersed environments that are highly susceptible to unexpected changes or variations. Given the fact, the strategic SOA approach could be effective in building an integrated management system capable of supporting the environments in an efficacious manner.

In this study, a service-based framework was established based on IBM's service oriented modeling and architecture (SOMA) methodology that offers various UML profiles at the service component level, i.e., an actual UML-based system materialization level. The approach is one of many SOA methodologies that are being offered to help design an efficient service-based integrated information framework. The Organization for the Advancement of Structured Information Standards (OASIS)'s SOA adoption blueprints were also among the alternatives. In SOMA, there is a life cycle in establishing SOA through a number of processes such as: business modeling and transformation; solution management; identification; specification; realization; implementation; and deployment monitoring and management. The present authors complied with this life cycle, though they simplified the rather complicated processes for customizing purposes, and used such new version to identify services and develop service-based applications. What is presented below is an example that indicates the fact that the development of SOA-based applications could produce desirable effects.

Let us suppose a situation where one's company is using Zigbee modules, i.e., components that are used for inter-equipment communication in an NICS environment, whose interface is designed with API base supplied by Corporation A. Due to performance and cost concerns, however, a switch to the API program offered by Corporation B appears to be inevitable. With a service-based application in place, a revision of the service that comprises the interface of Zigbee modules and a compilation process before distribution will save users cumbersome re-installation and set-up for each equipment. The entire updating work is done in only one intervention, which allows extremely fast and flexible responses to the changes. In contrast, with system materialization using non service-based formats, each equipment and program affected by the switch to a new Zigbee module API must have new installation, causing inefficiency and cost increase as well as difficulties in ensuring quick responses to a new system environment.

## The proposal of SOA based NICS Environment

In order to see the aforementioned SOA concept being effectively applied to the intelligent CSCM environment, i.e., NICS, the strategies must be designed in such a way that they are able to support the CSCM life cycle between factories and sites as an integrated whole. Based on this application strategy, Figure 4 below shows an SOA-based NICS environment — an example of service infrastructure concepts that organize intelligent equipment's use and inter-equipment communication interface on the construction supply chain management process into services, as they concern interaction between factories and sites.

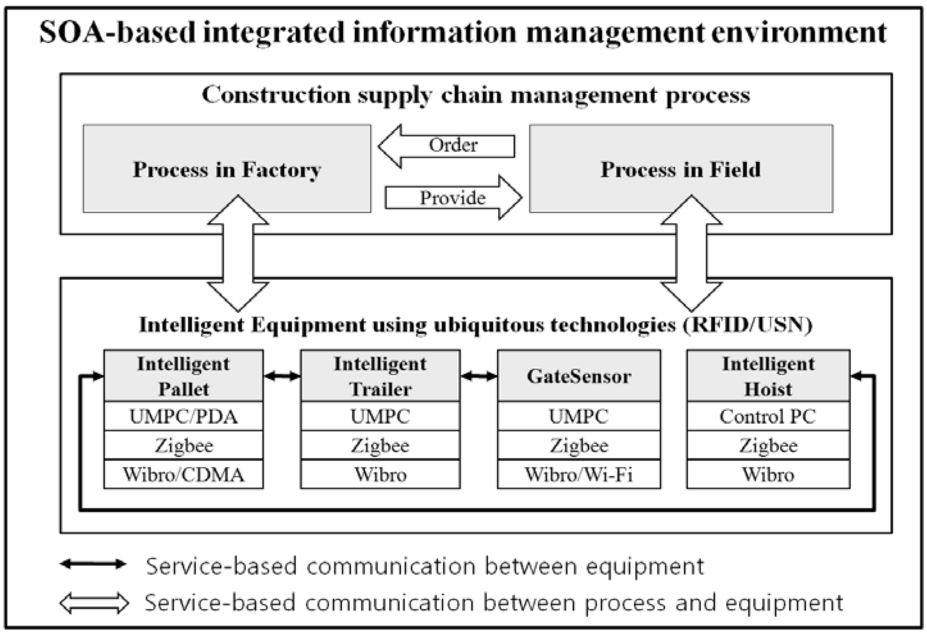


Figure 4. SOA-based NICS Environment

## Service Design for building SOA base NICS environment

The service, a core component of the SOA-based environment to be established, is defined as a re-usable service in atomic form and is the smallest unit that executes loosely-coupled interface functions. Therefore, an essential question in building the SOA-based framework is how smoothly the service can be subtracted from the system.

To answer one of the questions posed in this study, i.e., to design services that are universally applicable to an intelligent CSCM environment, the present authors: (a) analyzed the process wherein intelligent equipment are mobilized and operated in the NICS environment; (b) identified the functions needed to support the process; and (c) grouped some of the functions that can be identified as being atomic and that show similar characteristics into "partitions." The services thus defined based on the aforementioned process are represented in the service component model in Figure 5's UML component diagram. As indicated in the legend at the bottom of the right-hand side of the diagram, the model consists of "components," "ports," and "expose interfaces," with "dependency" referring to the link or relationship between the components.

The total number of the organized services was 25, of which 11 partitions were formed by grouping the ones with similar characteristics. Taking a closer look at each of the partitions, main features are summarized as follows: **Code Mgmt Service Partition** manages the NICS-operated codes; **Planning Service Partition** manages the schedule software programs (e.g., primavera, msproject), PMIS/ERP, and interfaces as related to material supply planning; **Order Service Partition** supports material-ordering processes; **Delivery Service Partition** handles material transport and electronic invoicing; **Quality Service Partition** supports quality testing at factories and sites; **Progress Service Partition** helps identify the status and process of intelligent equipment use; **Notification Service Partition** supports the notification activities between stakeholders (project participants); **Communication Service Partition** supports the read/write activities of

RS232C-based serial communication, RFIDtag, and Zigbee memory stream information; **Binary Data Transfer Service Partition** supports the transmission of the images captured by the webcameras installed at the GateSensor to their servers; and **Verification Service Partition** helps identify the validity status of entering/departing trailers at the GateSensor and the material release/delivery status to verify their compliance with planned locations when intelligent hoists and pallets loaded with materials are moving to the locations. When the system is used in an actual construction environment, the interface will be materialized by referring to the interfaces whose titles begin with "I."

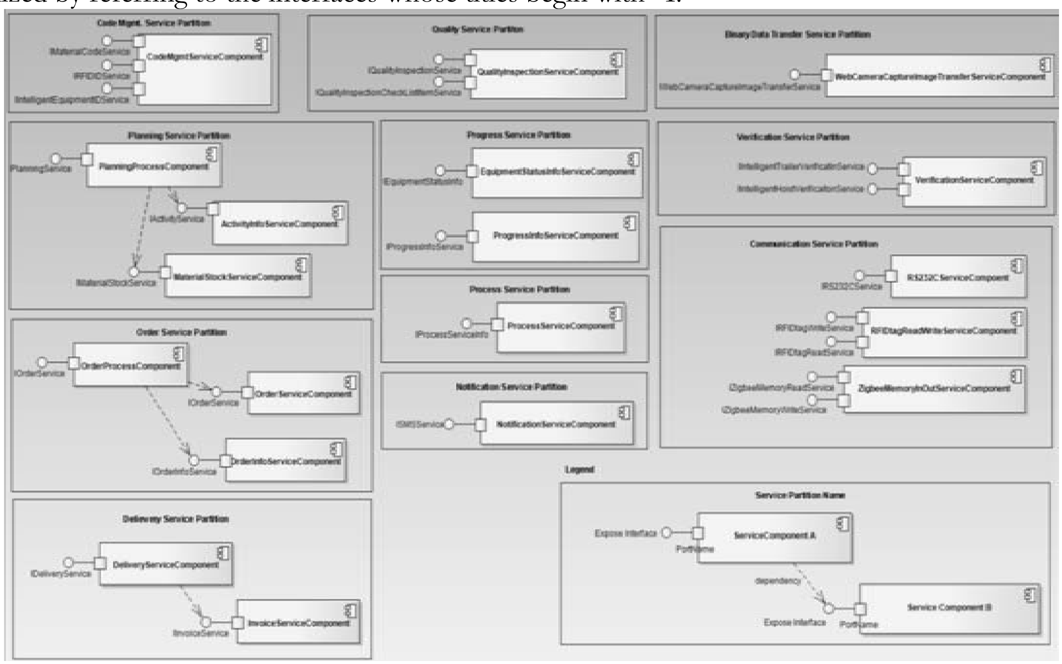


Figure 5. Service component model

## SOA based NICS Prototype system

In this study, a prototype system was developed to help prove that the identified service-based integrated information framework is able to support the NICS environment effectively. For the architecture of the prototype system, OASIS's SOA-RM (reference model), IBM's SOA reference architecture, and Microsoft's SOA reference architecture were reviewed to build a layered architecture, as shown in Figure 6 below, which has accommodated the characteristics of the NICS environment.

The prototype system used the windows communication foundation (WCF) which is supplied by .NET Framework 3.5 to host the core services and to effectively materialize an environment that enables inter-service transactions, with "C#" indicating codes. Figure 7 below shows a service-based application that has combined and organized the identified services as well as the intelligent trailer and pallet being used in the NICS environment, which have been built as re-usable services accommodating the functions that are needed in NICS operations via service binding and composition.

Throughout the building process of the prototype system, the present authors successfully verified that the service that is defined as an efficient interface (e.g., NICS) designed to help facilitate CSCM, which is a complicated distribution environment, is a fast and flexible model to accommodate various environmental changes (factors) as supported by a loosely-coupled comprehensive environment and that such service is effective in supporting the future CSCM environment.

## Conclusions

This research aimed to suggest an SOA-based system to help establish an effective comprehensive information management environment between construction equipment and systems as part of the NICS project based on RFID/USN technologies, and to help develop services accommodating the suggested environment as well as a prototype system. To build an efficient service-based integrated information framework, IBM's SOMA method was adopted to help identify a total of 25 services which were then organized into a service component model. Next, a layer-based system architecture was designed using OASIS's SOA-RM (reference model), IBM's SOA reference architecture, and Microsoft's SOA reference architecture as bases.

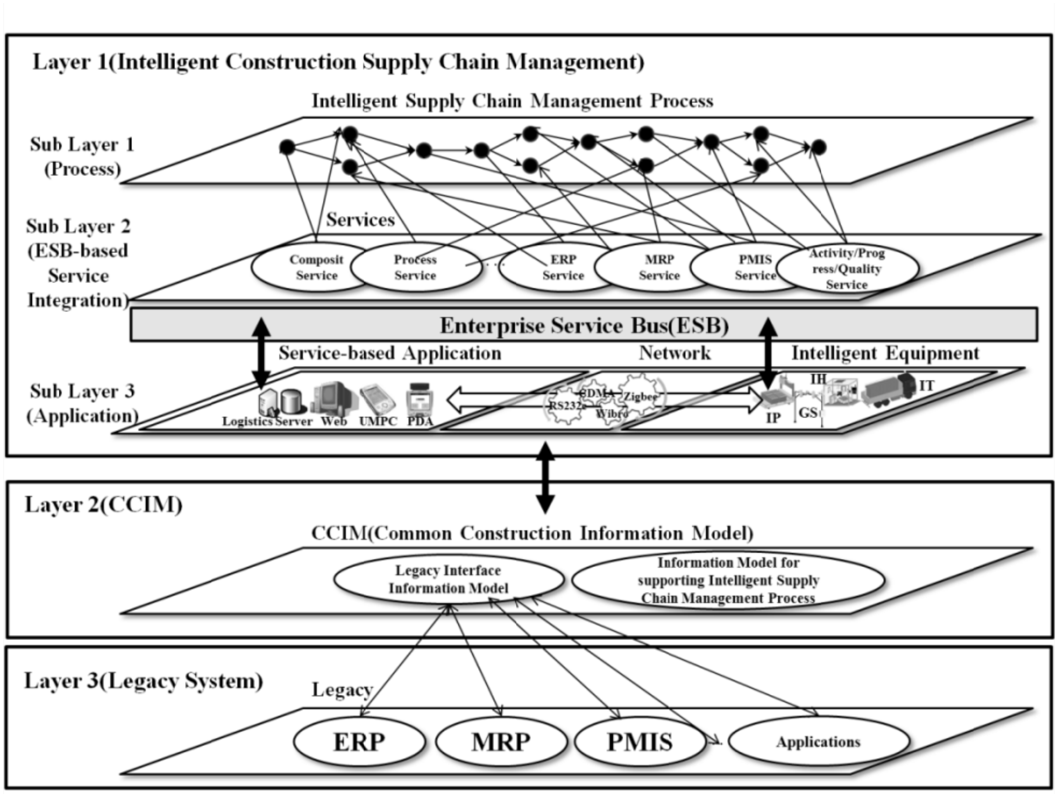


Figure 6. Layered-based System Architecture

The proposed SOA-based system environment design used the .NET Framework 3.5 WCF, which is capable of effectively supporting the service host as well as the service transaction. And a prototype system was developed to help determined whether or not the suggested design is applicable in a real-life environment, which is based on the service model and concept proposed in this study. In addition, the present authors verified that the proposed service-based information framework was a valid architecture that is able to quickly adapt to the CSCM environment where changes occur as frequently as in complicated heterogeneous and geographically dispersed information systems like NICS.

The results of this study are expected to be used in the future establishment of a full-scale NICS, as a core architecture of the system, and to help define and materialize re-usable services that come in the form of various functions required in an intelligent CSCM environment.

## Acknowledgement

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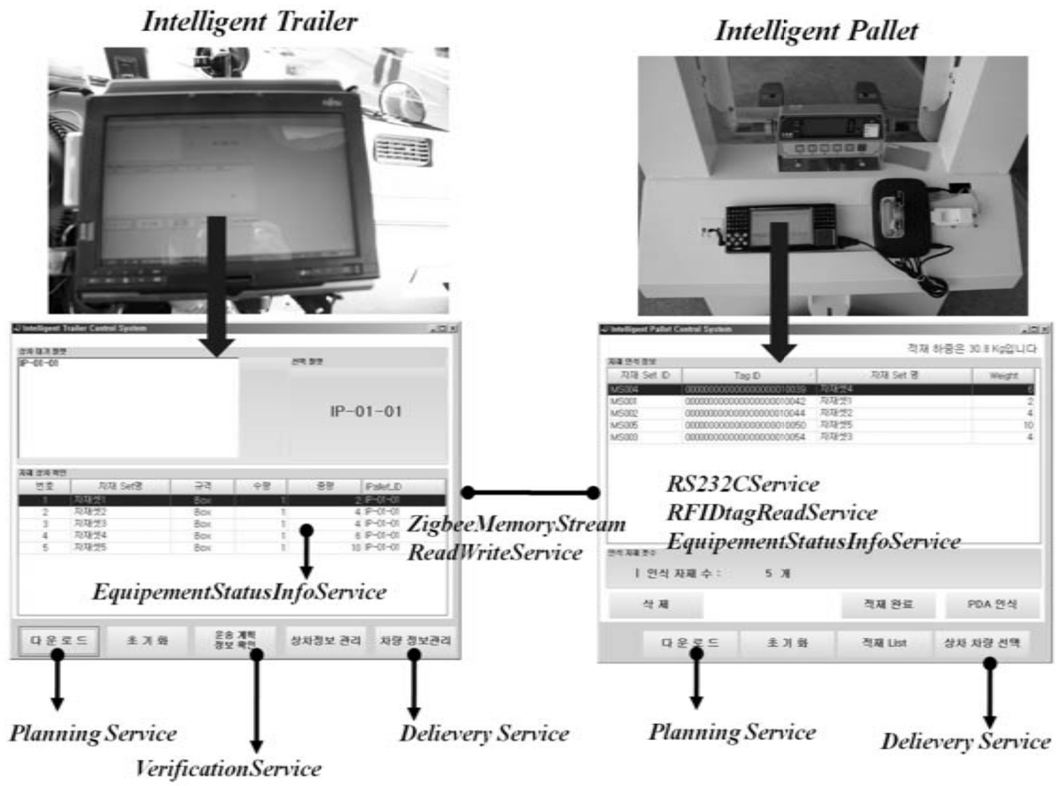


Figure 7. Service-based Application

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