Engineering Informatics:

State of the Art and Future Trends

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Introduction

- **Engineering informatics is an emerging engineering discipline combining information technology or informatics with a variety of engineering disciplines.**

- **It is interdisciplinary, focusing on the application of ICT (information and communication technology) to a variety of engineering disciplines.**

Computing Technology and Engineering Intertwining

- **Computer-aided design (CAD), computer-aided engineering (CAE), computer-aided manufacturing (CAM) are the terms that have appeared over the last four decades in the area of computing technology in engineering.**
- **Computing technology has had significant impacts on a variety of engineering disciplines.**
- **Meanwhile, computing technology in engineering has also promoted the advances in computing technology continuously.**
- **In this co-evolution process, computing technology and a variety of engineering disciplines have increasingly intertwined, as the development of the theory and practice in both disciplines (computing technology and engineering) influences each other.**

WFEO recognizing the importance of engineering information management

- **In early 1990s, the Committee on Engineering Information of the World Federation of Engineering Organizations (WFEO) started studies on training engineering students with information management background.**

- **The results of the study were published by UNESCO (Michel 1994).**

Excerpts from reports of US National Science Foundation or US National Academies

- **“The structuring of design information and data integration are critical requirements for data sharing between designers separated physically and in time, as well as between companies, vendors and customers. Standards do not yet exist for modeling many engineering and organizational parameters that are essential for design specification and analysis, nor are there standards for structuring rational for decisions and design procedures used” (National Research Council 1991).**

- **“Data communication in a heterogeneous system, validation, and consistency of data, representation of textual and geometrical data, …, analytical models of manufacturing processes are all risky areas of research, requiring multiyear, cooperative efforts. Solutions to these problems are needed…” (National Research Council 1995).**

Excerpts from reports of US National Science Foundation or US National Academies

- **“Interdisciplinary collaborations will be especially important for implementing comprehensive processes that can integrate the design of mechanical systems with the design of electrical systems and software. Successful collaborations, however, will first require overcoming incompatibilities between emerging technologies and the existing technological infrastructure and organizational cultures” (NSF 2004).**

- **“For many organizations, a fundamental change in the engineering culture will be necessary to take advantage of breakthroughs in advanced computing, human-machine interactions, virtual reality, computational intelligence, and knowledge-based engineering…” (National Academy of Engineering 2005).**

From EIM to proposing the use of the term "engineering informatics"

- **In 2006, Mocko et al indicated that Engineering Information Management (EIM), specifically the development of information models, is becoming increasingly important to engineering.**

- **In 2008, Subrahmanian and Rachuri first proposed to use the term "engineering informatics" to cover the theory and practice in which computing technology and engineering are interfacing each other.**

- **As such, it has been started recognizing the need for a scientific subject called engineering informatics, although the subject has not yet been formally recognized as a scientific and engineering discipline.**

The Evolution of the Subject

- **In 2008, Subrahmanian and Rachuri further indicate that the history of computing technology and engineering shows a trend of increasing sophistication in the type of engineering problems being solved.**

- **Early CAD was primarily based on computational algorithms and models. Then came the engineering use of AI, driven by theories of cognitive science and computational models of cognition. More recently, models of collaboration, and the acquisition and representation of collective knowledge have been introduced.**

- **Following this trend, engineering informatics can be defined as “the study of use of information and the design of information structures that facilitate the practice of engineering and of designed artifacts that embody and embed information technology and science to achieve social, economic, and environmental goals”.**

Strands of concepts that support the proposing of engineering informatics

- **Subrahmanian and Rachuri identified several strands of concepts that support the proposing of engineering informatics as a distinct discipline that interfacing engineering and informatics.**

- **As computer scientists or engineers cannot solve engineering informatics problems in the context of engineering systems alone, engineering informatics is an interdisciplinary and collaborative effort.**

- **In other words, the lack of required backgrounds among computer scientists in engineering and engineers in computing technology has lend to develop a new interdisciplinary subject--engineering informatics.**

Similar movements have been made in individual engineering discipline

- Construction taken in the broadest sense of the word to include building, civil engineering, structural engineering.
- In the construction engineering discipline, initially, several names have been used for the interdisciplinary field related to both construction engineering and computing technology such as “computer integrated construction”, “computing in civil engineering”, and “information technology in construction”.
- The most commonly used term are “information technology in construction” or “construction IT”. They were coined in the middle 1990s.
- According to Turk, “years later more sober voices claim that many of the problems in the construction industry, that could have been solved by information technology, are not solved, however not only due to technical issues. It seems appropriate, therefore, to remove the word technology and leave just ‘*construction informatics*’ (CI)”.

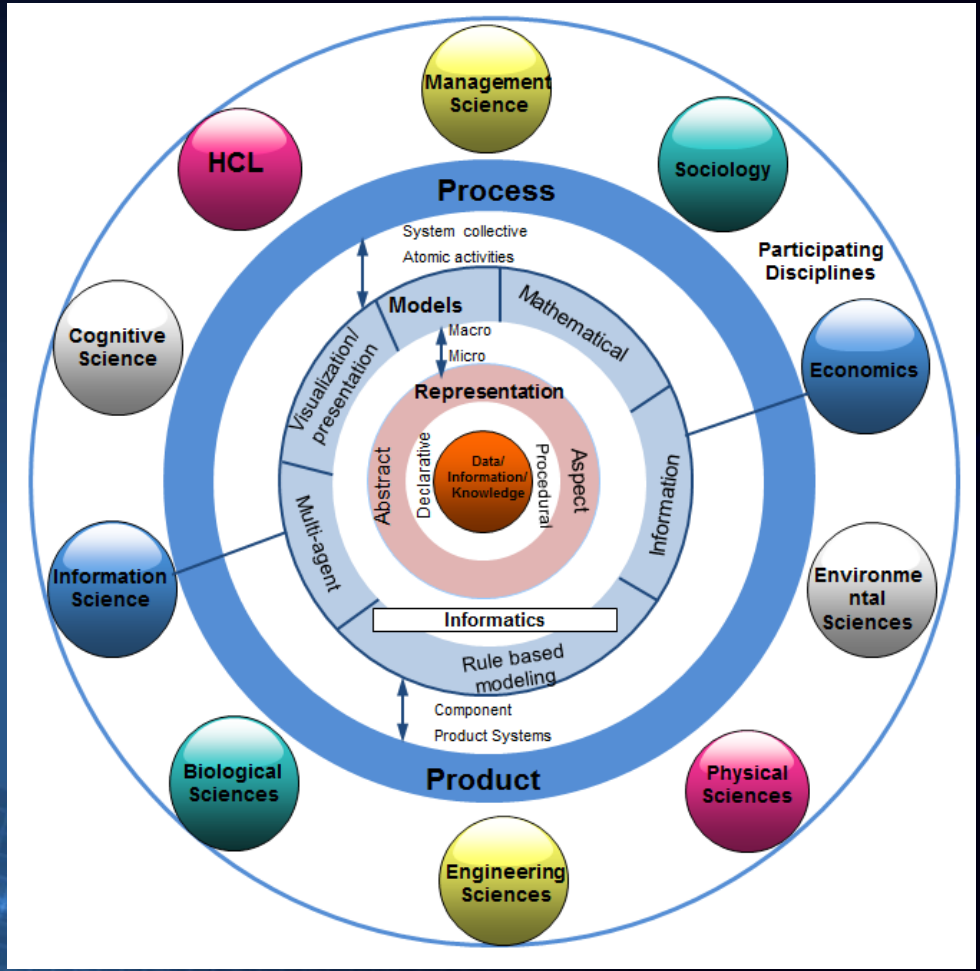
Engineering informatics is considered as a distinct discipline

- **Engineering informatics is thus considered as a distinct discipline, at the interface between engineering and informatics, in the same vein as bioinformatics, medical informatics.**

Scope of Engineering Informatics

- **In 2008, Subrahmanian and Rachuri proposed their view on the scope of engineering informatics.**

The scope of engineering informatics proposed by Subrahmanian and Rachuri in 2008 (Figure 1)



Scope of Engineering Informatics

- **In Figure 1, the inner set of circles marked as informatics covers the fundamental activities associated with informatics in general.**
- **The next circle, denoted by Product and Process, identifies the multi-level, multi-scale modeling activities of products and processes.**
- **The role that informatics plays in engineering products and processes has been becoming significant in past decades.**
- **The outer circles show the inputs to engineering informatics from a number of disciplines that provide the domain knowledge and methods and tools.**

Why Engineering Informatics emerges?

- **In 2007, Regli indicates that, in the information technology in engineering, although there have been great strides made by academic and commercial entities in the past decades, it would seem that the fundamental problems of information integration remain the same.**

- **In 2008, Subrahmanian and Rachuri indicate the numerous incompatibilities in information exchange and coordination.**

- **The delays that occurred in Airbus 380 and Boeing 787 are examples of the problems of this nature. The information integration within or across industrial sectors is still a dream.**

- **Regli and other researcher have indicated the key technological issue of engineering informatics is "*the apparent lack of fundamental progress in areas of information integration*".**

Industrial Information Integration Engineering (IIIE)

- **Before the need for engineering informatics was formally presented in 2007 and term “engineering informatics” was coined in 2007 and 2008**

- **In 2005, two international organizations, IFIP (International Federation for Information Processing) and IEEE, formerly proposed and recognized a scientific and engineering discipline called Industrial Information Integration Engineering (IIIE).**

Industrial Information Integration Engineering (IIIE)

- **In June 2005, at a meeting of the International Federation for Information Processing (IFIP) Technical Committee for Information Systems (TC8) held at Guimarães, Portugal, the committee members intensively discussed and formally recognized the important role played by industrial information integration and the innovative and unique characteristics of Industrial Information Integration Engineering (IIIE) as a scientific sub-discipline.**

- **IIIE is a set of foundational concepts and techniques that facilitate the industrial information integration process.**

- **IIIE comprises methods for solving complex problems when developing IT infrastructure for industrial sectors, especially in the aspect of information integration.**

Industrial Information Integration Engineering (IIIE)

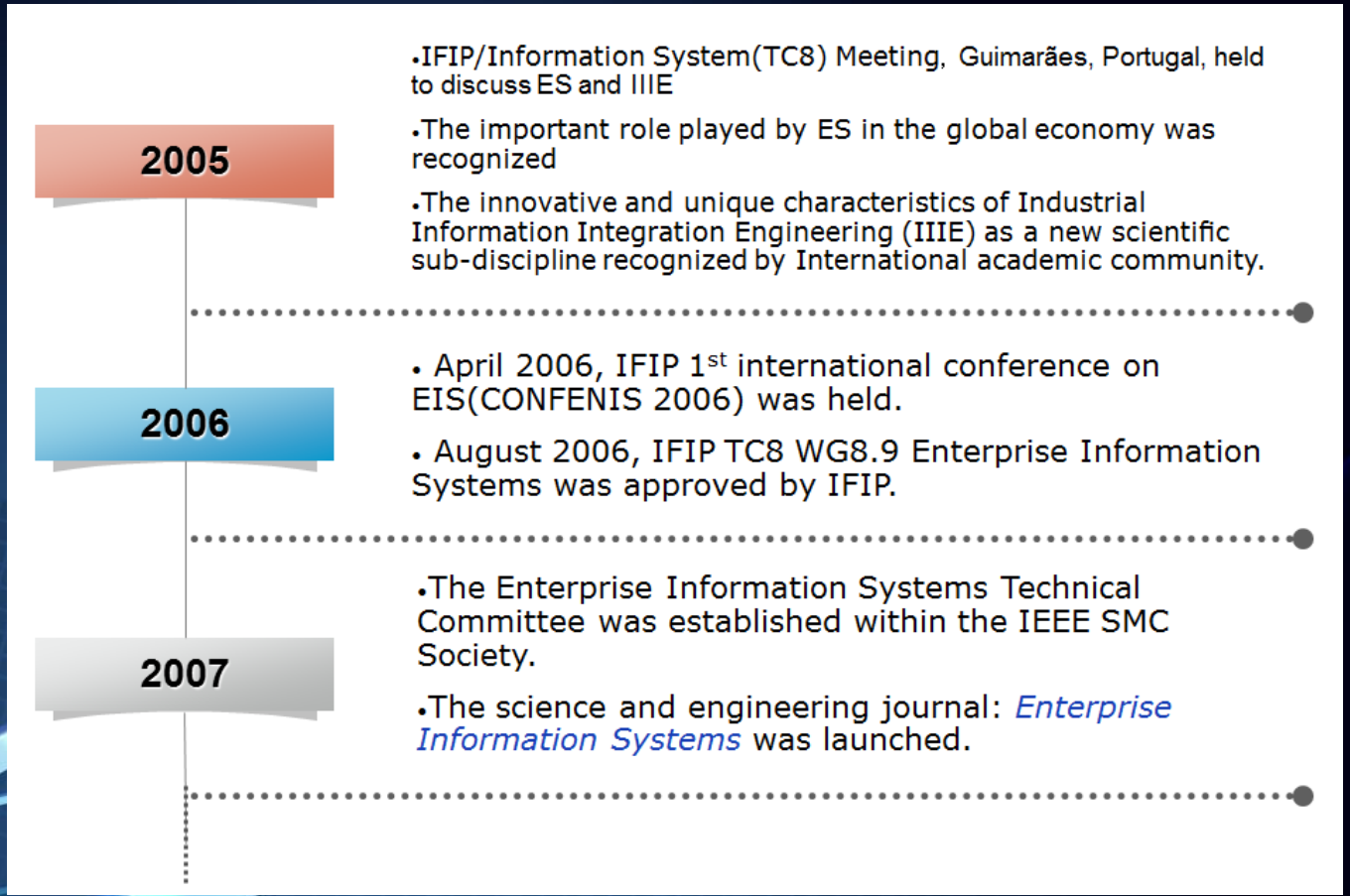
- **It was decided at this meeting that the IFIP First International Conference on Research and Practical Issues of Enterprise Information Systems (CONFENIS 2006) would be held in 2006 in Vienna, Austria.**

- **In August 2006, at the IFIP 2006 World Computer Congress held in Santiago, Chile, the IFIP TC8 WG8.9 Enterprise Information Systems was established.**

- **In 2007, the Enterprise Information Systems Technical Committee was established within the IEEE SMC Society.**

- **To further respond to the needs of both academicians and practitioners for communicating and publishing their research outcomes, the science and engineering journal entitled *Enterprise Information Systems*, exclusively devoting itself to the topics of IIIE, was launched in 2007.**

IIIE Discipline History (Figure 2)



IIIE Overlapping with the Scope of Engineering Informatics

- **The concept of IIIE emphasizes multiple aspects, including one of the major aspects which completely overlapping with the scope of engineering informatics: engineering information integration.**

- **As Regli and other researchers have indicated, the key technological issue of engineering informatics is "*the apparent lack of fundamental progress in areas of information integration*".**

- **In 2011, the concept of information integration has been recognized and applied to large-scale chemical engineering project (Jin and Lin 2011).**

- **In 2012, scholars recognized that enterprise information integration can overcome various data sharing problems (Yin 2012).**

This Presentation

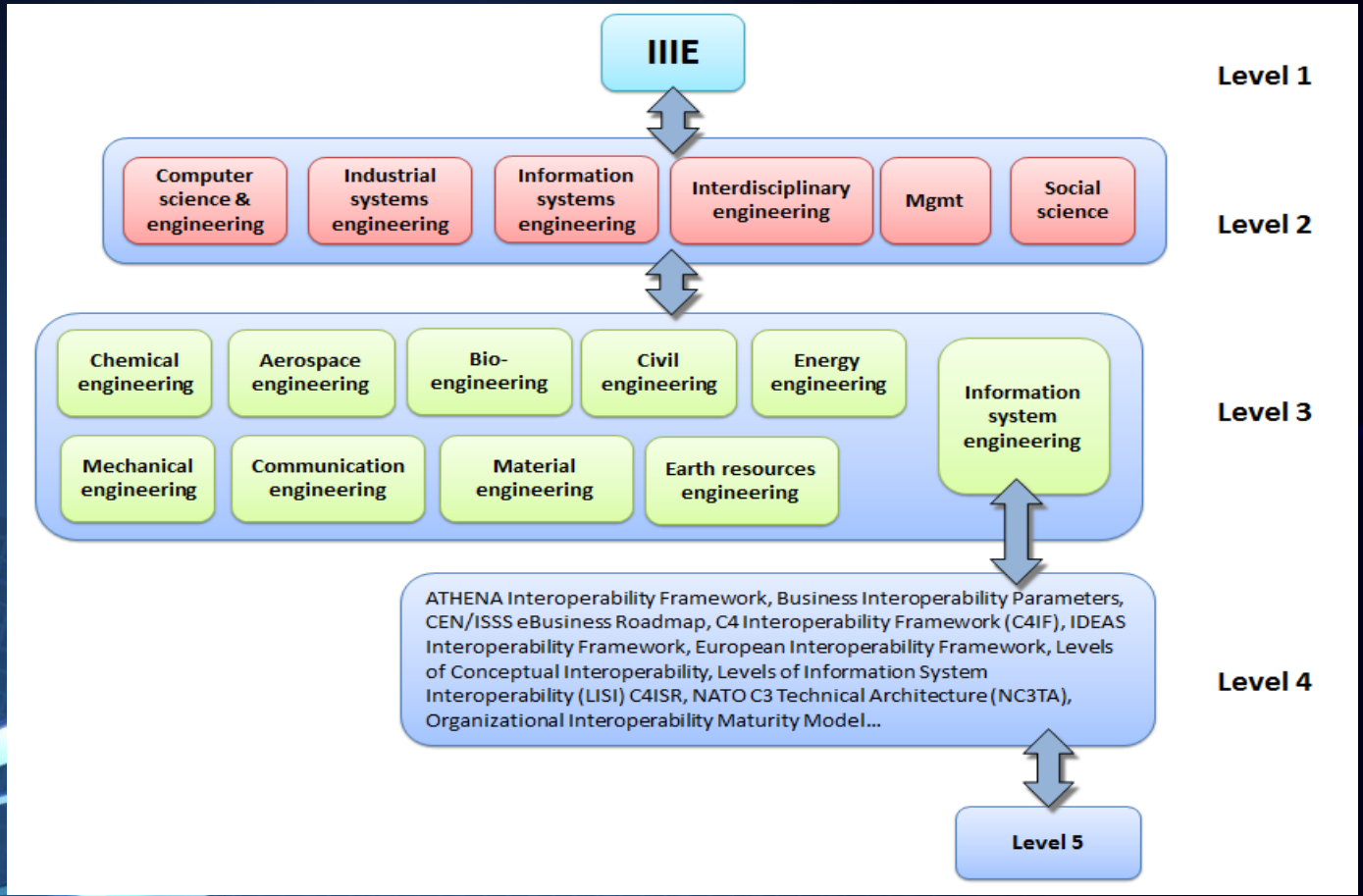
- **This presentation is focusing on one of the major aspects of IIIE which completely overlapping with the scope of engineering informatics: engineering information integration.**

- **The objective of this presentation is to introduce to the communities of engineering and engineering informatics the current development and future opportunities that exist in engineering information integration, but it is by no means meant to be exhaustive.**

- **We will discuss the relationship between enterprise information integration and engineering information integration.**

- **We will also describe major techniques or technologies in enterprise information integration applicable to engineering informatics.**

Discipline Structure of IIIE (Figure 3)



Discipline Structure of IIIE

- As an interdisciplinary discipline, IIIE interacts with scientific disciplines such as mathematics, computer science, and almost every engineering discipline among the twelve engineering disciplines defined by the US National Academy of Engineering.
- At the methodological layer, IIIE interacts with computer science and engineering, industrial systems engineering, information systems engineering, and interdisciplinary engineering.
- The US National Academy of Engineering is organized into twelve sections, each representing a broad engineering category. IIIE interacts with almost every one of them.
- At the application layer, IIIE interacts with aerospace engineering, bioengineering, civil engineering, energy engineering, communication engineering, material engineering, and earth resources engineering.
- In addition to the scientific and engineering disciplines, IIIE also interacts with management and social sciences.
- Management and social sciences can be important. For example, any effective engineering projects rely on effective management.

Discipline Structure of IIIE

- **IIIE can advance and integrate the concepts, theory, and methods in each relevant discipline and open up a new discipline for industry information integration purposes which is characterized by its interdisciplinary nature.**

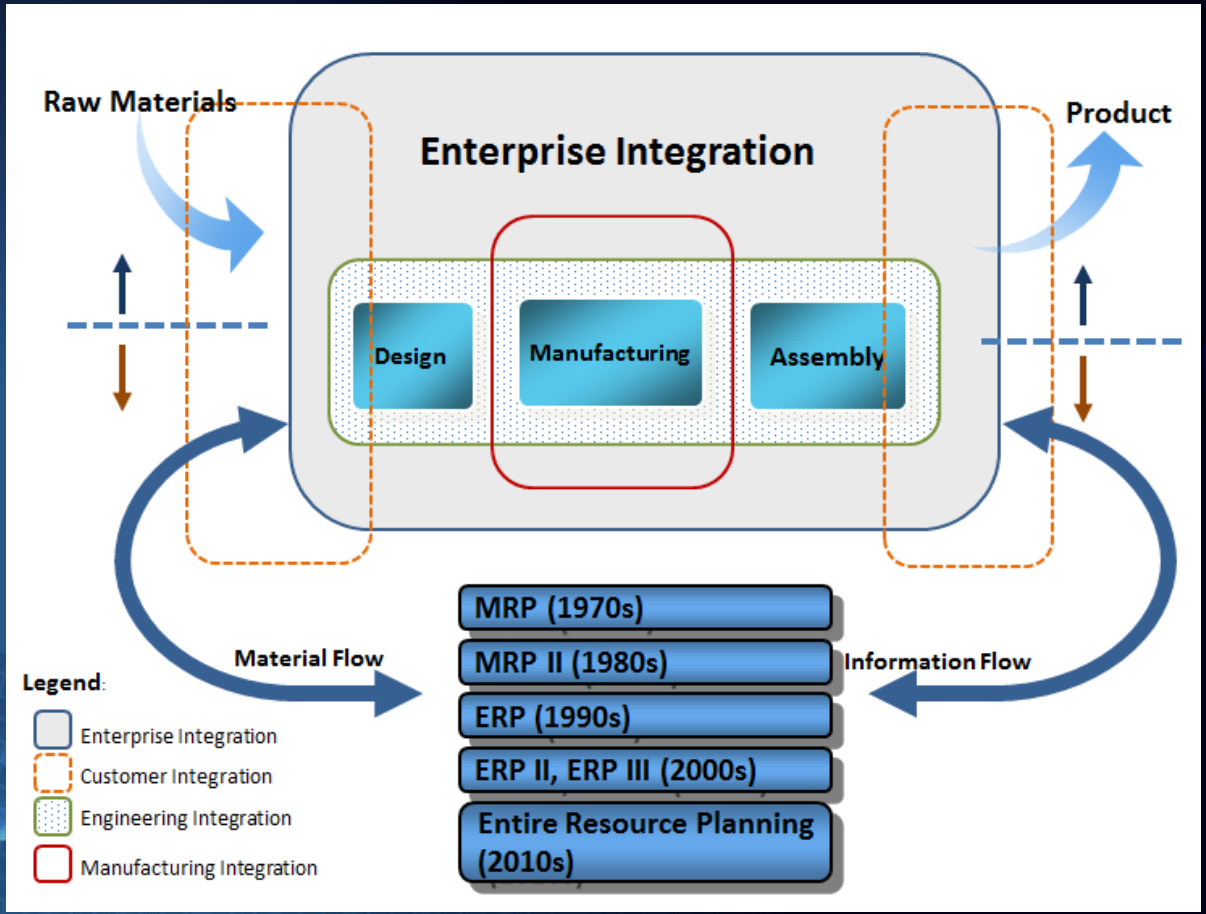
- **Figure 3 shows IIIE at the top level; relevant scientific, engineering, management, and social science disciplines at the second level; and application engineering fields at the third level. At the fourth level and the levels below, many relevant frameworks, theories, and models can be listed.**

- **Figure 3 can be huge in size, in order to cover all of the details involved.**

- **For example, enterprise interoperability is involved with frameworks such as the ATHENA Interoperability Framework, Business Interoperability Parameters, the CEN/ISSS eBusiness Roadmap, C4 Interoperability Framework (C4IF), the IDEAS Interoperability Framework, the European Interoperability Framework, Levels of Conceptual Interoperability, Levels of Information System Interoperability (LISI) C4ISR, NATO C3 Technical Architecture (NC3TA), and the Organizational Interoperability Maturity Model.**

The Relationship between Engineering Integration and IIIE

- The relationship between engineering integration, manufacturing integration, customer integration, and enterprise integration (Figure 4)



Earlier Efforts on relating Engineering Integration with Enterprise Integration

- **In today's global competition atmosphere, industrial systems including engineering systems need to be constantly and smoothly re-engineered in order to allow them to respond to the fluctuating market and to technological evolution.**

- **In 1980s, MRP II systems, as enterprise systems in IIIE, interface with engineering design systems to receive BOM and routing information. However, the interface is not always advanced, as it is unable to pass critical information back to the engineering design system.**

- **In 2000, engineering integration became one of the main components of enterprise systems.**

- **Figure 4 shows the relationship between engineering integration, manufacturing integration, customer integration, and enterprise integration.**

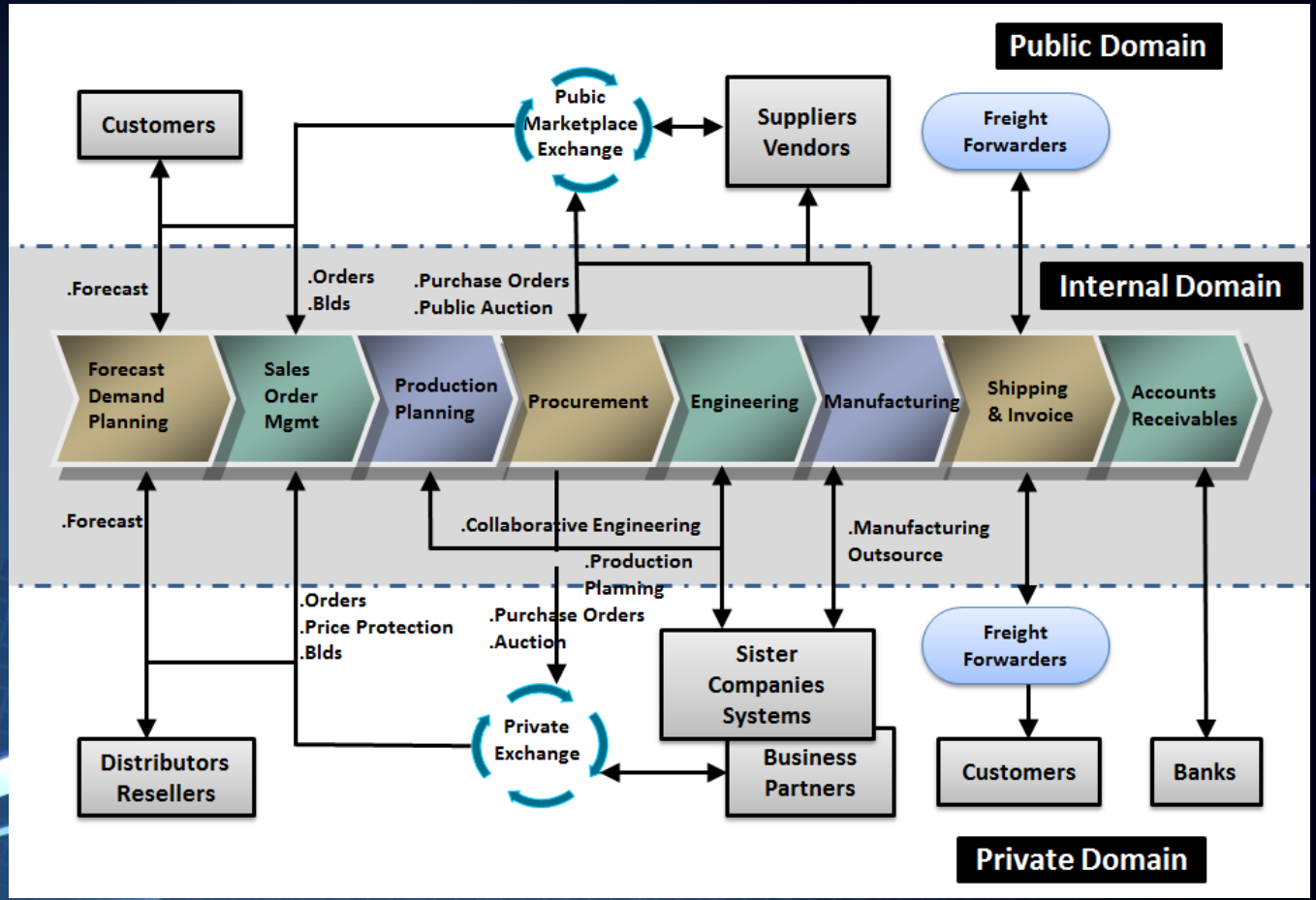
The Expanding Scope of Engineering Integration

- **At different stages of a product's life cycle, from its requirement specifications to its conceptual design, to its more detailed structure design, and finally to its production, engineering knowledge must be integrated.**

- **A complete integration includes the design process, product data management, integration with customers, integration with suppliers, integration with the rest of the organization, and project management.**

- **The ways in which the engineering division integrates with the rest of divisions in an enterprise have been intensively researched.**

The Needs of Expanding Scope of Engineering Informatics in Collaborative Manufacturing Environment (adapted from Ho & Lin, 2004) (Figure 5)



IIIE and Engineering Integration

- **Figure 5 further shows the relationship between engineering integration, manufacturing integration, customer integration, and enterprise integration.**

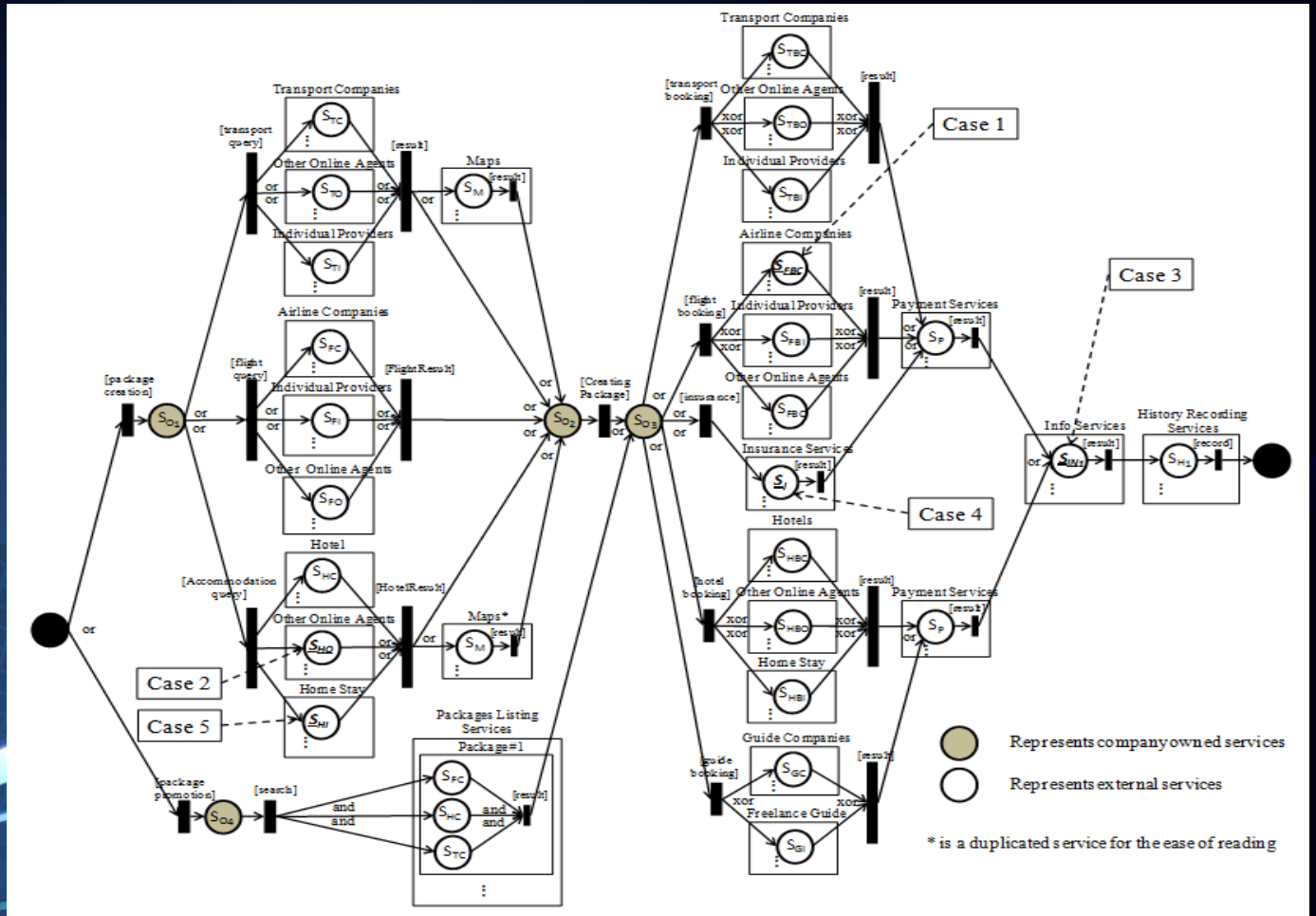
- **The research on engineering integration is becoming more prevalent now. Research has recently been conducted on the methods and models for establishing enterprise systems for large-scale engineering projects.**

- **In the following, we will introduce the main enabling technologies for engineering informatics as well as IIIE, which include Business Process Management, Information Integration and Interoperability, Enterprise Architecture and Enterprise Application Integration, and Service-oriented Architecture (SOA).**

Business Process Management

- **Engineering design process modeling can inherit methods and approaches developed in business process management.**
- **Theiben, Hai and Marquardt introduced a methodology for modeling, improving, and implementing design processes in chemical engineering. The method inherits some methods developed in the domain of business process reengineering and workflow management.**
- **IIIE enables the integration of business processes throughout an organization with the help of Business Process Management (BPM).**
- **BPM is an approach that is focused on aligning all of the aspects of an industrial organization in order to promote process effectiveness and efficiency with the help of information technology.**
- **Through business process modeling, BPM can help industries standardize and optimize business process, increasing their agility in responding to the changing environment for competitive advantage, accomplishing business process reengineering, and realizing cost reduction.**

Scientific Modelling of Process/Workflow: An Example (Figure 6)



Information Integration and Interoperability

- **In 2008, Park et al indicate that *Engineering Collaboration* is inevitable in the various engineering phases including product design phase, analysis phase, inspection phase, and so on.**
- **However, in *Engineering Collaboration,* sharing engineering data generated from CAD/CAE systems is technically very difficult due to the complexity and size of the data.**
- **Besides, heterogeneous CAD/CAE systems make it difficult to accomplish data sharing for engineering collaboration purpose.**
- **In 2008, Subrahmanian and Rachuri indicate the numerous incompatibilities in information exchange and coordination. The delays that occurred in Airbus 380 and Boeing 787 are examples of the problems of this nature. The information integration within or across industrial sectors is still a dream.**
- **Regli and other researcher have indicated the key technological issue of engineering informatics is "the apparent lack of fundamental progress in areas of information integration".**
- **Although there has been several different explorations of different theories of design and manufacturing, progresses yet to be made that can provide effective methods for information integration.**

Information Integration and Interoperability

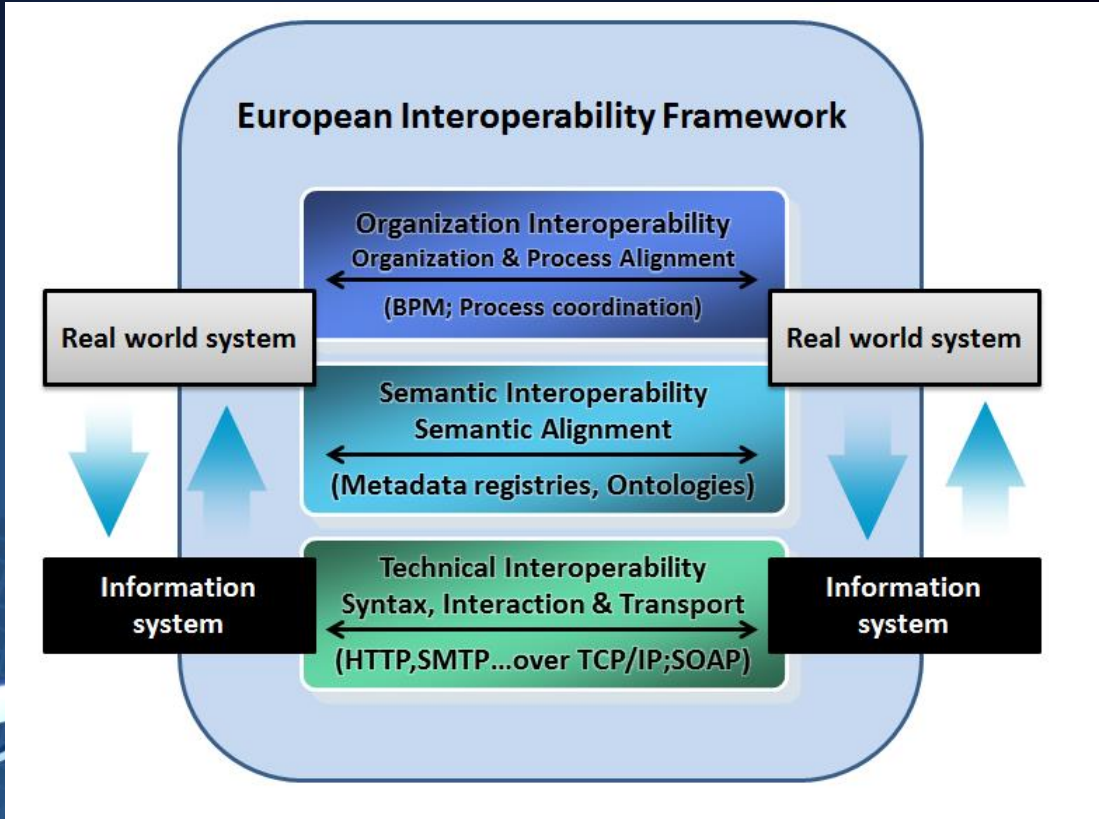
- **In IIIE, enterprise systems technologies are increasingly moving toward inter-organizational information integration.**

- **An inter-organizational enterprise system is aiming at providing a higher level system related to activities that involve the coordination of business processes (both intra- and inter-organizational) and is able to provide an integrated architecture to organizations.**

- **The integration of inter-organizational systems is a complex task. Several frameworks have been proposed for information integration.**

- **However, as indicated by Wolfert et al., the contents of these frameworks are not comprehensive, and an overall framework of information integration has yet to be developed.**

An Example of Information Integration Framework: European Interoperability Framework (Figure 7)



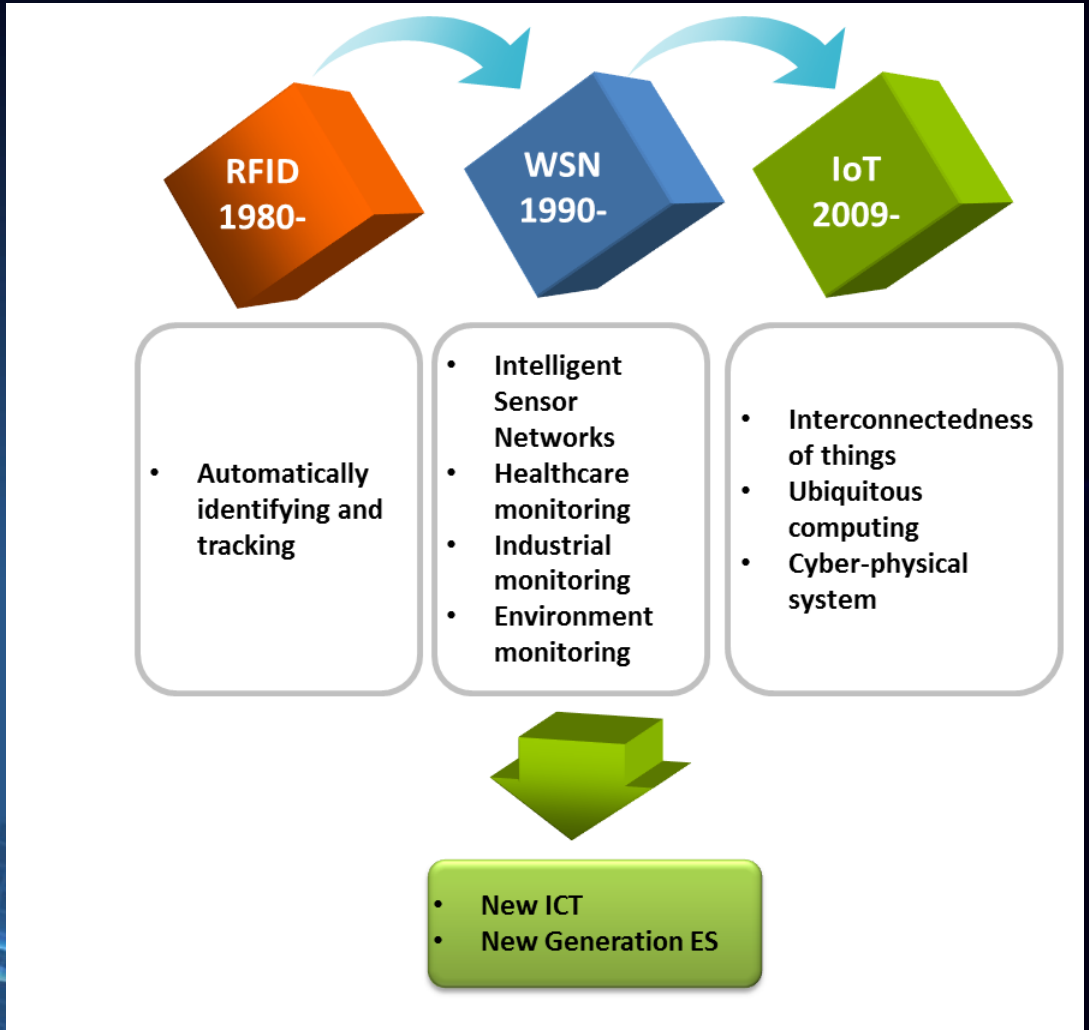
Information Integration and Interoperability

- **It is expected that IIIE integration will attract more efficient and effective methods for automated engineering management in which the seamless integration of inter-organizational systems is highly expected.**

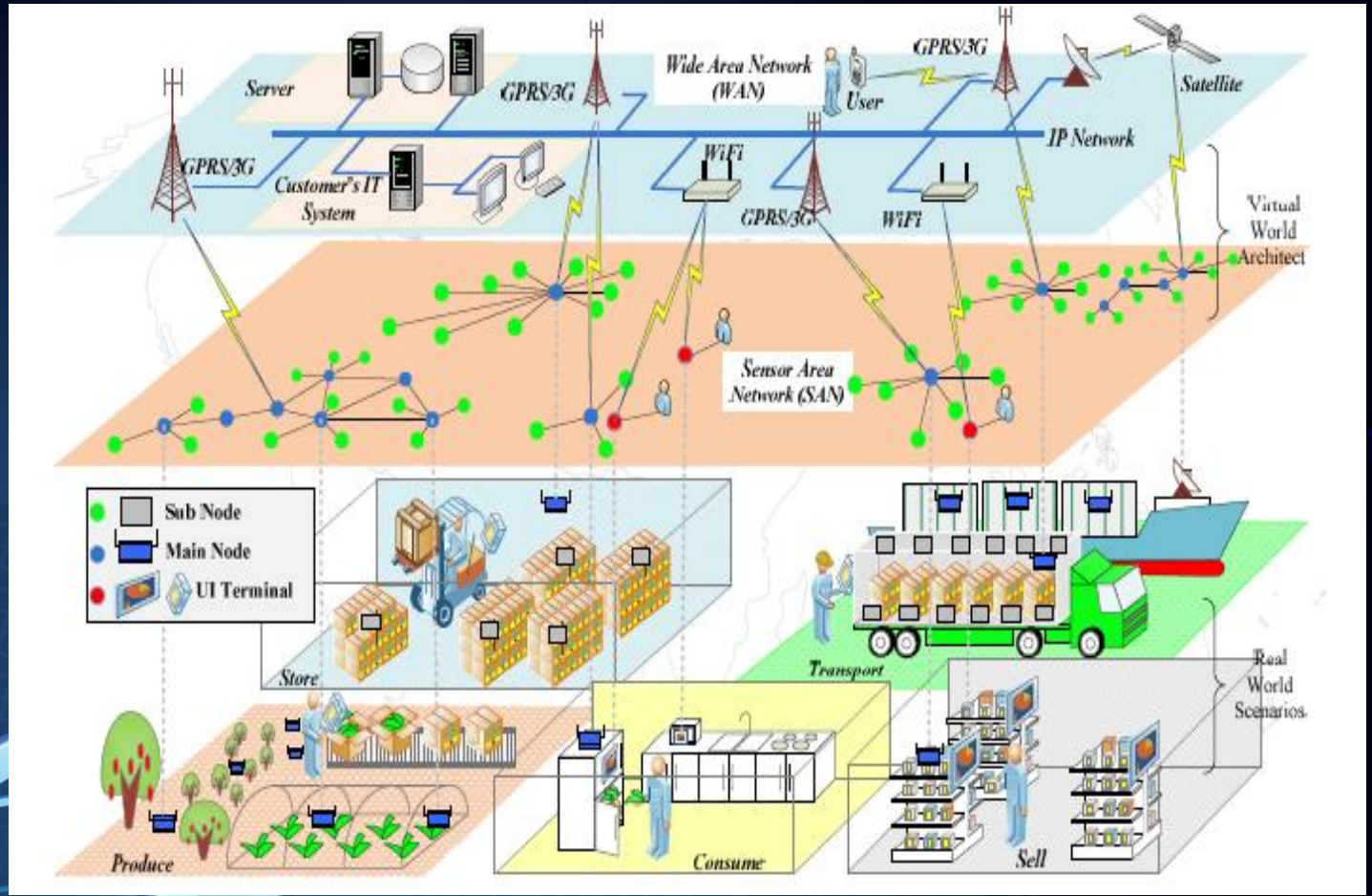
- **Among the new technologies, IoT has attracted much attention. The envisioned applications include information to be collected from IoT.**

- **IoT is impacting information integration and Engineering Informatics.**

IoT and related technology are impacting new ICT, enterprise systems, and engineering informatics (Figure 8)



An Example of Information Integration using IoT in Food Industry (Figure 9)



Enterprise Architecture and Enterprise Application Integration

- "***Interdisciplinary collaborations will be especially important*** **for implementing comprehensive processes that can integrate the design of mechanical systems with the design of electrical systems and software.** ***Successful collaborations, however, will first require overcoming incompatibilities between emerging technologies and the existing technological infrastructure and organizational cultures*****".**

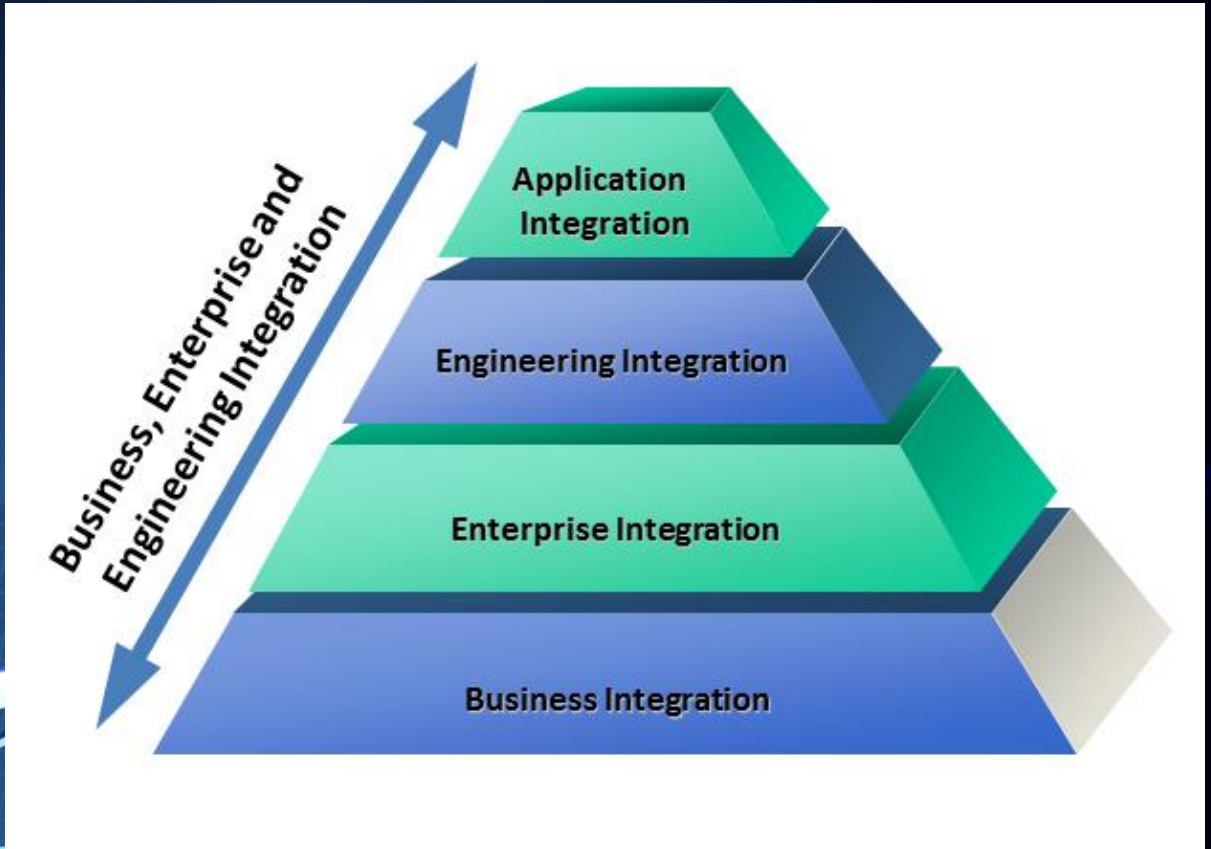
- **An enterprise architecture (EA) defines the scope of the enterprise, the internal structure of the enterprise, and its relationship with the environment.**

- **EA comprises main enterprise components such as enterprise goals, organizational structures, business process, information infrastructure, as well as engineering infrastructure.**

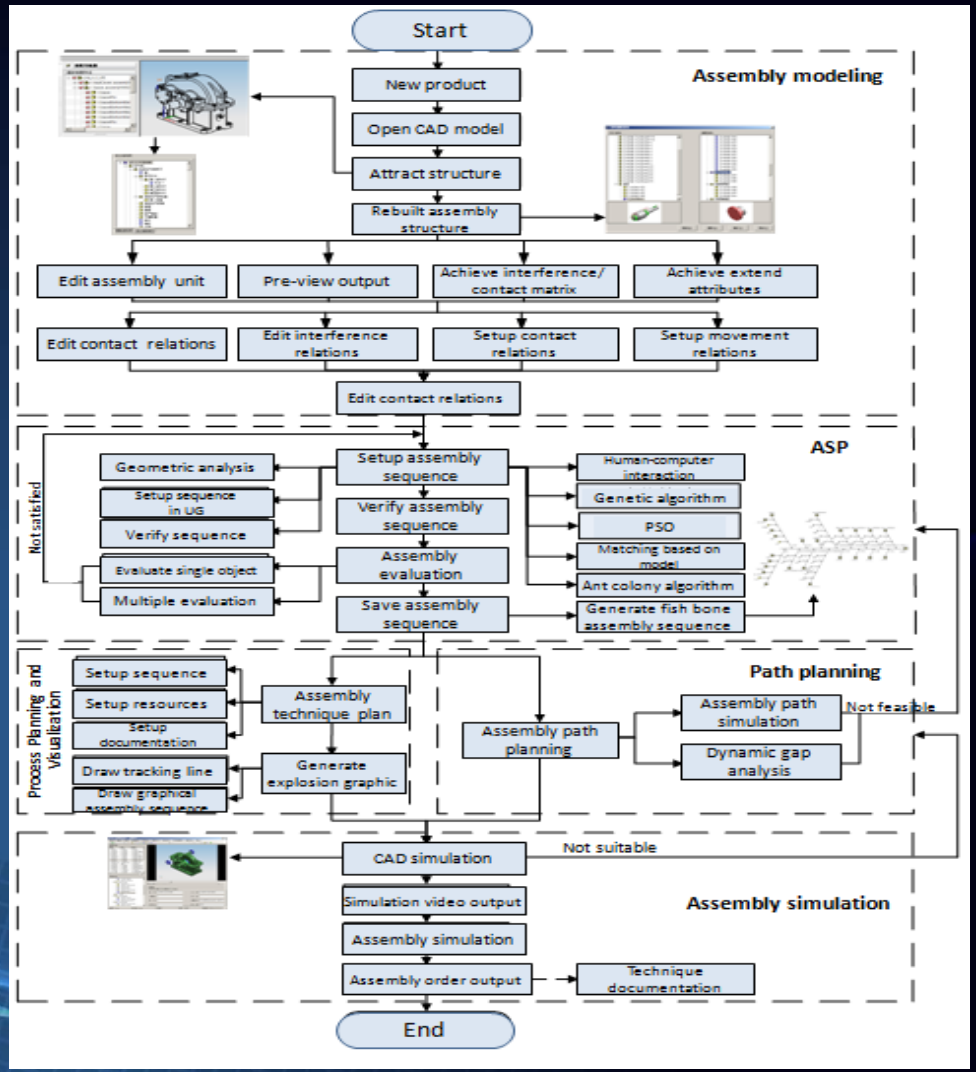
- **Representing the architecture of an enterprise correctly and logically will improve the performance of an organization.**

- **This includes innovations about the structure of an organization, business process re-engineering, and the quality and timeliness of the information flow that also represents engineering aspects.**

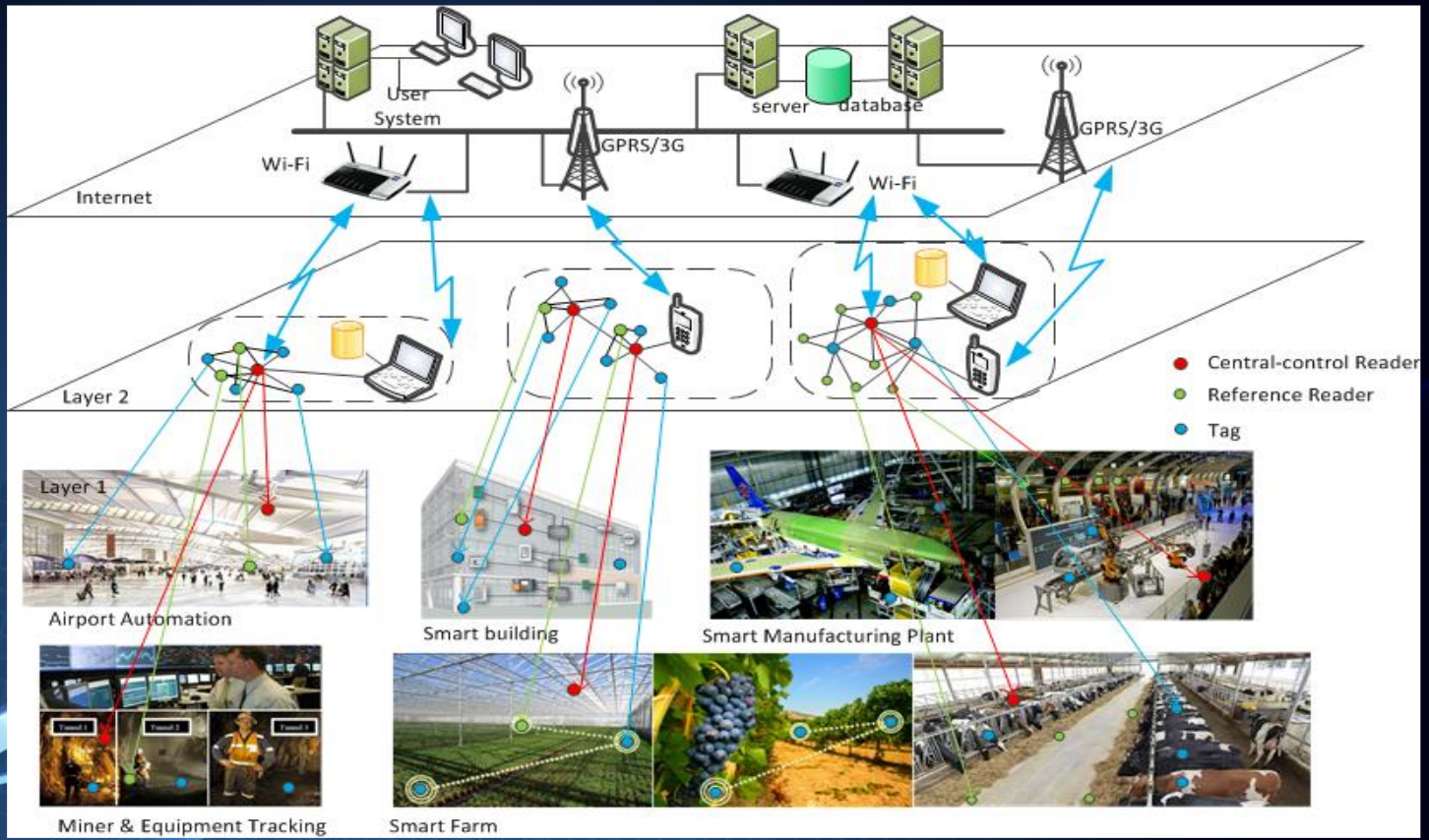
From Business Integration to Engineering Integration (Figure 10)



Assembly Planning Integration within Engineering Integration (Figure 11)



Examples of Engineering Integration and EAI using IoT in Manufacturing and Service Sectors (Figure 12)



Enterprise Architecture and Enterprise Application Integration

- **Enterprise integration within the framework of EA has become a key issue for many enterprises looking to extend business processes through integrating and streamlining processes both internally and with partners in the supply chain.**
- **It consists of plans, methods, and tools.**
- **Typically, an enterprise has existing legacy systems which are expected to continue in service while adding or migrating to a new set of applications.**
- **Integrating data and applications is expected to be accomplished without requiring significant changes to existing applications and/or data.**
- **To address this issue, a solution that can help to achieve quality integration is referred to as Enterprise Application Integration (EAI).**

Enterprise Application Integration

- **In general, those enterprise applications that were not designed as interoperable can be integrated on an intra- and/or inter-organizational basis.**
- **EAI aims not only to connect the current and new system processes, but also to provide a flexible and convenient process integration mechanism.**
- **Through creating an integrative structure, EAI connects heterogeneous data sources, systems, and applications intra- or inter-organizationally.**
- **By using EAI, intra- or inter-organizational systems can be integrated seamlessly to ensure that different divisions or even enterprises can cooperate to each other, even using different systems.**
- **A complete EAI offers functions such as business process integration and information integration, since the core of the EAI technology is business process management.**
- **Through the coordination of the business processes of multiple enterprise applications and the combination of software, hardware, and standards together, engineering components in enterprise systems can share and exchange data seamlessly in a supply chain environment.**

Service-oriented Architecture (SOA)

- **Srinivasan, Lammer and Vettermann indicate the importance of SOA in engineering informatics. Their paper describes how product information sharing service has been architected and implemented using SOA.**

- **Service-Oriented Architecture (SOA) represents the latest trend in integrating heterogeneous systems which has great potential in engineering informatics.**

- **It has received much attention as an architecture for integrating platforms, protocols, and legacy systems, and it has been considered as a suitable paradigm that helps integration, since it is characterized by simplicity, flexibility, and adaptability.**

Service-oriented Architecture (SOA)

- **SOA represents an emerging paradigm for engineering informatics to use in order to coordinate seamlessly in the environment of heterogeneous information systems.**

- **Enabling the timely sharing of information in the cooperative systems, and developing flexible large-scale software systems for engineering applications.**

Challenges

- **Although the technologies and applications introduced in this paper are currently not yet fully used in engineering, they are expected to have great potential to play a major role in near future.**

- **Efforts focusing on blending the capabilities of existing technology and the emerging technologies are needed.**

- **With this blending, engineering will be able to harness the power of current and emerging technologies to dramatically improve the performance of industrial information integration including engineering informatics by adopting new technologies.**

Challenges

- **Research indicates that the successful engineering informatics practice relies upon more sophisticated technologies than those that are available now.**
- **Research also indicates that training engineers for 21 century with the capacity of using engineering informatics presents a challenge to us.**
- **Lack of a single stakeholder is another challenge. As such, it is difficult to evaluate economic costs and benefits of information interoperability.**
- **In addition, developing universal metrics for information integration and solving “system of systems” design can also be challenging.**
- **The interdisciplinary nature of engineering informatics implies another challenge as the complexity level rising as it involves a multiplicity of informatics and a variety of engineering subjects.**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Thanks!