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Cloud Manufacturing

Distributed Computing Technologies for Global and Sustainable Manufacturing

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Preface

Owing to globalization, modern manufacturing activities are geographically distributed across the world and away from comprehensive value creation within single enterprises. Original Equipment Manufacturers (OEMs) and partners, among which Small and Mid-sized Enterprises (SMEs) are the main portion, have formed complex and decentralized information chains. Setting up own manufacturing information systems would have meant a massive capital expenditure for enterprises. Moreover, enterprises are usually insufficient in resource and expertise to maintain such complex systems to achieve global and sustainable management. Novel distributed technologies, such as Cloud Computing, are the new-generation supplement, consumption, and delivery models for the over the Internet provision of dynamically scalable resources and utility computing, can support multiple companies to deploy and manage services for accessing and exploiting over the Internet. As thus, a Cloud Manufacturing system or service, which serves multiple companies to deploy and manage manufacturing information and sustainable management services for accessing and exploiting over the Internet, can provide a cost-effective, flexible, and scalable solution to global manufacturing enterprises by sharing complex database and software, with lower support costs on top of that.

This book is aimed at updating the latest research and development in this emerging and important R&D field. A new paradigm called Cloud Manufacturing is introduced, which stands for novel scalable service-oriented sustainable and globally distributed manufacturing systems. In this book, original and innovative chapters have been included to address the major challenges of developing distributed and Cloud Computing technologies for manufacturing systems and services, with scientific and rigorous foundations as well as application values. Covered topics include: innovative design of distributed and Cloud architectures for global and sustainable manufacturing management; distributed process planning and scheduling in global and sustainable manufacturing; modern evolutional algorithms in Cloud Manufacturing systems and services; sustainable manufacturing practice and Cloud Computing; collaborative product and manufacturing service systems; distributed 3-dimensional data sharing technique for Cloud and Web applications, and relevant user surveys, applications, and case studies in aerospace and defense industries, remanufacturing, and socialized manufacturing society.

In Chap. 1, the essential features of Cloud Computing are discussed, followed by a Cloud Manufacturing concept. A service-oriented system called Interoperable Cloud-based Manufacturing System (ICMS) is then presented. ICMS provides a Cloud-based environment integrating the existing and future manufacturing resources by packaging them using the Virtual Function Block mechanism and standardized description.

In Chap. 2, a distributed disassembly planning service to support Waste Electrical and Electronic Equipment remanufacturing (WEEE) is reported. In this chapter, a Particle Swarm Optimization-based selective disassembly planning method embedded with customizable decision-making models and a novel generic constraint handling algorithm is developed. Industrial cases on Liquid Crystal Display televisions have been used to verify and demonstrate the effectiveness and robustness of the research in different application scenarios.

As outsourcing demands related to machining task are appearing to be increasingly explosive in recent years, especially in SME manufacturing enterprises, a new production and operation phenomenon characterized by outsourcing machining services has emerged consequently. In order to address the need, Chap. 3 presents a novel Cloud Machining Community mainly focusing on outsourced tasks related to machining processes and parts. A use case fashioning a torque arm of an airplane undercarriage is studied so as to demonstrate the feasibility and applicability of the proposed framework and technologies.

The purpose of Chap. 4 is to confirm which factors actually affect adoption of the Cloud Computing technology in manufacturing companies. The factors are assessed by a randomly selected sample of 47 working professionals in the United Kingdom through an online questionnaire. Analysis of the result shows that Security, Cost, Service Availability, Compliance, and Perceived Usefulness are factors of concern that organizations would have to deeply consider before moving to the Cloud.

Sustainability becomes essential to today's manufacturing systems and a new concern is how to evolve the existing paradigms to meet new challenges using distributed and Cloud Computing technologies. The objectives of Chap. 5 are to examine the manufacturing requirements in a wider scope, to revisit the existing paradigms to clarify the limitations and bottlenecks, and eventually to identify future research directions toward sustainable manufacturing. Within the context, this chapter focuses more on Reconfigurable and Cloud manufacturing system paradigms, and highlights the future endeavors toward better sustainability.

Sustainability has also become a critical driving force shaping the future of Waste Electrical and Electronic Equipment (WEEE) management and remanufacturing. In Chap. 6, lifecycle information and flow management is investigated to enable transition from the current "management authority-centric reporting model for WEEE" to a new "globally distributed and sustainable management model for WEEE". In order to achieve the target, case studies on LCD television WEEE are conducted to understand supply chain information flows and recovery and remanufacturing processes. Based on that, information/flow framework design for WEEE management is explored.

One of the challenging problems that hinder the development of Cloud-based collaborative systems is the contradiction of large CAD files and the limited speed to share them over the Internet and Web. In Chap. 7, a new 3D streaming technology to transfer design and manufacturing visualization data via the Internet and Web is reported.

Chapter 8 presents a paradigm of designing by services, describes the devising of a service-oriented architecture for collaborative product development systems for this paradigm, discusses the key enabling technologies involved, and introduces the development of a collaborative simulation using service-oriented computing as a case study of software systems implementation.

Recent developments in wireless technologies have created opportunities for developing next-generation manufacturing systems with real-time traceability, visibility, and interoperability in shop-floor planning, execution, and control. Chapter 9 proposes a referenced infrastructure of Ubiquitous Manufacturing (UM), in which a Smart Gateway and a real-time work-in-progress management system based on smart objects such as RFID/Auto-ID devices and Web service technologies are designed to improve the optimal planning and control of the entire shop floor. The presented framework is demonstrated through a near real-life simplified shop floor that consists of typical manufacturing objects.

Chapter 10 presents a review of the R&D literature on distributed collaborative engineering and applications, from the technologies of the 1980s to today's state-of-the-art. Research challenges and opportunities on the research areas are also discussed and highlighted. Distributed and Cloud Computing technologies applicable to distributed collaborative engineering and applications are discussed in detail.

In Chap. 11, the landscape of Cloud Computing is described and a focus is put on the view on the possibility of implementing this new concept in the military world. The strengths and the weakness that the implementation of Cloud Computing can introduce in the military operations are highlighted.

The 11 chapters in this book provide an update and overview of the latest technological development and applications in relevant research areas. This book is believed to make significant contributions to the literature, and can be used as a textbook or reference for mechanical/manufacturing/computer engineering graduate students and researchers for efficient utilization, deployment, and development of distributed and Cloud manufacturing systems, services, and applications.

During the development of this book, we have received invaluable input and gotten great support from the chapter authors. Their commitment, enthusiasm, professionalism, and technical expertise made this book possible. We are also grateful to the publisher for supporting this project, and would like to thank Mr. Anthony Doyle, Senior Editor for Engineering, and Ms. Grace Quinn, Editorial Assistant, for their constructive assistance and earnest cooperation.

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We hope readers find this book informative and useful.

November 2012

Weidong Li
Jörn Mehnen

Contents

Chapter 1
ICMS: A Cloud-Based Manufacturing System

Xi Vincent Wang and Xun W. Xu

Abstract Nowadays, Cloud Computing technology is providing a new way to do business by offering a scalable, flexible service over the Internet. It creates new solutions and opportunities to the modern enterprises, including the manufacturing industry. In this chapter, the essential features of Cloud Computing are discussed followed by a Cloud Manufacturing concept. In the second part, a service-oriented system called Interoperable Cloud-based Manufacturing System (ICMS) is proposed. ICMS provides a Cloud-based environment integrating existing and future manufacturing resources by packaging them using the Virtual Function Block mechanism and standardized description.

1.1 Introduction

Cloud Computing refers to the delivery of computing as a service, instead of a traditional product. According to the definition of National Institute of Standards and Technology (NIST) [1, 2], Cloud Computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g. networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. In a Cloud Computing environment, decentralized

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consumers are provided by flexible and measurable service from the resource pool. The key spirit of the Cloud concept can be summarized as the capability of providing distributed, fast-responding, on-demand and quantifiable services.

In the past few decades, many novel technologies have been proposed to improve the environment of manufacturing business, e.g. collaborative manufacturing, virtual manufacturing, agile manufacturing, etc. Amongst these solutions, Cloud Computing technology provides a promising solution and an even broader definition for the concept of "Design anywhere and make anywhere (DAMA)".

In the first half of this chapter, Cloud Computing technology related to the manufacturing perspective is discussed, followed by a review of the related research work. In the second half, a Cloud-based platform is proposed to achieve an interoperable distributed manufacturing environment.

1.2 Cloud Manufacturing: Cloud Computing with a Manufacturing Perspective

Cloud Computing includes both the software service delivered to the user and the systems and hardware that are able to provide the service in need. The former is defined as Software as a Service (SaaS) and the later as Infrastructure as a Service (IaaS) and Platform as a Service (PaaS). Under the broad concept of Cloud, everything is treated as a Service (XaaS).

1.2.1 From Cloud Computing to Cloud Manufacturing

To precisely define and classify the Cloud model, there are four deployment types, i.e. private, community, public, and hybrid Cloud. To support these concepts or architecture, platforms are provided by the major software vendors such as Amazon's Elastic Compute Cloud (EC2) [3], Google's App engine [4], Microsoft's Azure [5] and Sun's Cloud [6]. According to a recent Forrester research [7], Cloud Computing business has reached $40.7 billion globally in 2010 while impacting 948 billion Information and Communications Technology (ICT) market. Even though some obstacles are observed, for instance the unpredictability and confidentiality, it is still predicted that Cloud Computing market will keep growing and developing in the future [8].

As a service-centric solution, users or the enterprise will benefits from Cloud Computing features such as low cost, flexibility, mobility and automation. In the Cloud Computing environment, an enterprise does not need to purchase the software/hardware that is rarely used. Based on the "pay-as-you-go" principle, the cost can be reduced including less maintaining and labor expenses. For the service provider, the updating and re-producing procedure is simplified as well. By updating the codes in the provider cloud, traditional shipping, re-packaging cost is made avoidable, so is the cost. The user is provided by more flexible computing methods. There are more choices for companies to process a specific task, and more freedom to launch/terminate a service with less issue. The users/employees could access the application/information via various devices connected to the network. It improves the organization with an environment of distributed collaboration. In an industry scenario, users are enabled to get the real-time device status, for instance storage information, thanks to the network sensors without the need to visit the scene. For both cloud users and providers, new application publishing and updating is made easier. By updating the server, all the personal/enterprise would get the latest service without any additional effort.

Nowadays, manufacturing business may not survive in the competitive market without the support of computer-aided capabilities (CAx) and Information Technology (IT). Cloud technology can improve the environment of product design, manufacturing process management, enterprise resource planning, and manufacturing resource management by providing a globally optimized solution. As mentioned above, a broader DAMA can be described as completing designing and manufacturing procedures via clouds, while the users and business partners are loosely connected by a cloud-centralized network. It is therefore natural to bring cloud concept into manufacturing business. Figure 1.1 illustrates typical market-oriented cloud architecture. It is possible to map manufacturing resources to the

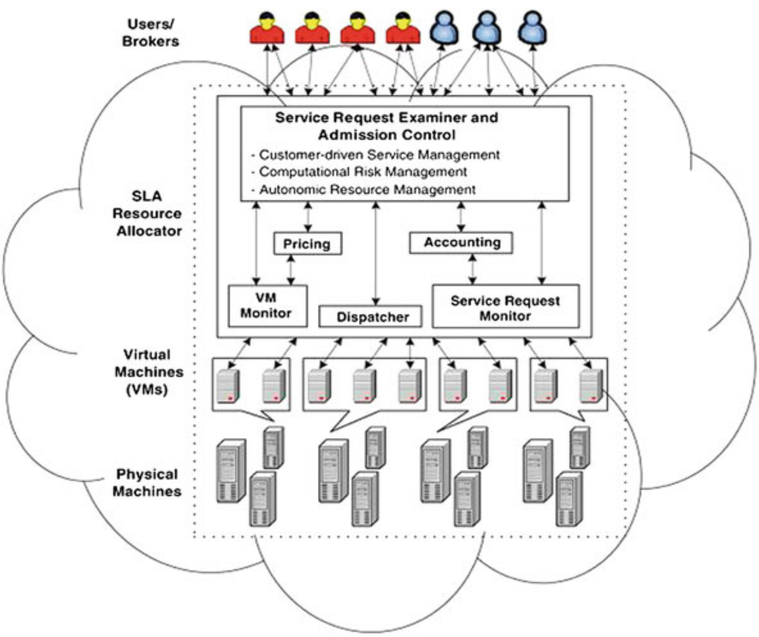

Fig. 1.1 Market-oriented Cloud Architecture [9]

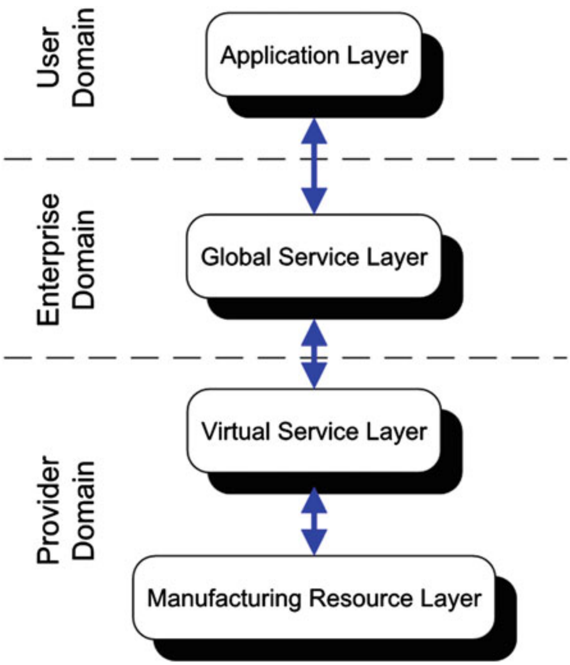

Fig. 1.2 Layered Architecture of a Cloud Manufacturing System

cloud-based architecture and deploy computing capabilities and hardware in a service-centric environment.

To address Cloud technology in manufacturing context, Xu proposed the definition of Cloud Manufacturing as "a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable manufacturing resources (e.g., manufacturing software tools, manufacturing equipment, and manufacturing capabilities) that can be rapidly provisioned and released with minimal management effort or service provider interaction [10]". In this piece of work, a Cloud manufacturing system framework is proposed consisting four layers, manufacturing resource layer, virtual service layer, global service layer and application layer (Fig. 1.2).

1.2.2 Manufacturing Resource Requirements

Manufacturing resources can be integrated in the Manufacturing Resource Layer during the lifecycle of the product. This includes both physical manufacturing resources, e.g. materials, machines, equipment, devices, and manufacturing capabilities existing in the software/hardware environment, e.g. product document, computing capability, simulation/analysis tools and etc. At this layer, resources are modeled in a harmonized information technology and ready to be delivered and re-used. For product data, portability and longevity have to be guaranteed in the Storage Cloud. Open data format and open Application Programming Interfaces (APIs) can be used. Among the solutions proposed so far, STEP (the STandard for Exchange of Product data [11]) is one of the most successful formats up to the task. STEP provides mechanisms for describing the product information throughout the lifecycle. As a neutral data format, STEP also provides different Application Protocols for specific utilities and applications. For instance, AP203 [12] is one of the most popular product design data format that is used for data exchange between different CAD software tools. Furthermore, AP224 [13] provides feature-based definitions to a STEP-compliant CAD/CAPP/CAM system. As an extension of STEP, STEP-NC has been developed to model the machining capability of CNCs. Meanwhile, the capability and variety of heterogeneous resources also needs to be described. Research has been carried out to describe the manufacturing resource in a scalable and standardized methodology [14–16]. Hence, both the provider and the user are able to compare different solutions and make a reasonable choice.

1.2.3 Virtual Service Requirements

The key functions of this layer are to (a) identify manufacturing resources, (b) virtualize them, and (c) package them as Cloud Manufacturing services. Comparing with a typical Cloud Computing environment, it is much more challenging to realize these functions for a Cloud Manufacturing application.

A number of technologies can be used for identifying (or tagging) manufacturing resources [17–19], e.g. RFID, computational RFID, wireless sensor networks (WSN), Internet of things, Cyber Physical Systems, GPS, sensor data classification, clustering and analysis, and adapter technologies. Some of them have been proposed to be connected with cloud architecture [20, 21].

Manufacturing resources virtualization requires a high-quality result from the physical or logical resources. Manufacturing hardware can be virtualized/simulated by Virtual Machine Monitoring or Virtual Machine Managing systems [22]. As an agent based monitoring tool, MTConnect™ provides a standardized open protocol for data exchanging over the network [23–25]. By using MTConnect™ agents, the machine tools and other process equipment can communicate with each other. Figure 1.3 shows how MTConnect™ can be utilized to feed data for the event cloud and generate virtualization output in the end.

1.2.4 Global Service Requirement

The requirements of a suite of cloud applications (e.g. PaaS) are deployed at this layer. Physical devices and machines are connected by internet-related

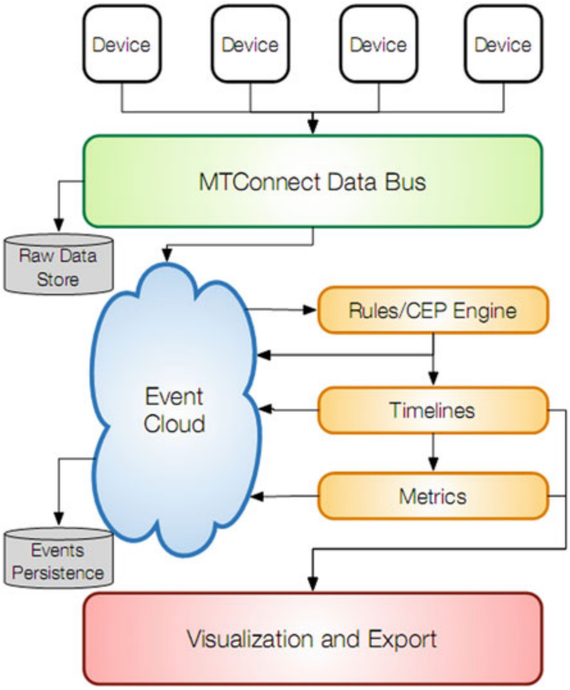

Fig. 1.3 Complex reasoning engine via MTConnect™ [23]

technologies, i.e. RFID, intelligent sensors and wireless sensor networks. Thus at this layer, the request of the user, especially the enterprise requirements should be evaluated and realized. The service should have the flexibility that allows the user to choose, modify and terminate it. Essential advice and diagnose report should be there when needed. Virtual services, for instance computing capability, manufacturing capabilities, partial infrastructure management and configurations, should be delivered to this layer to fulfil customer requests.

For the cloud provider, the supervision and pricing system should be implemented towards user/enterprise's need. It is necessary to analyse the participant's specific requirement, allocate the service in need and deliver an optimum solution to the end user. QoS (Quality of Service) and Pricing system is in need afterwards [26]. The service provider is responsible to maintain the computing environment, execute the manufacturing tasks and take care of outputs in the virtual environment, plus guaranteeing the quality of both the service and the products.

1.2.5 Application Requirement

The application layer provides terminals to end-users and brokers. The user is able to access the virtual applications/resources via Graphical User Interfaces (GUI). Different from enterprise-level solutions, activity-based cost calculating mechanism can be introduced to this level. The provider is capable of different measurement or metering mechanism while offering different kinds of services. Additionally, for both Application and Global Service layer, error-tolerance mechanism is also necessary. When a software/hardware fault appears, the mechanism should keep the service working by advising the user with solutions or alternative options.

In the Application Lever of a Cloud Manufacturing system, confidentiality and security requirement is deemed as major considerations [27]. User/Company sensitive data can be protected by technologies, for example,

- Data compressing/Encrypting mechanisms
- Firewall/packet filters for communications amongst layers and users
- Virtual LAN offering remote and scoped communications.

1.2.6 Research Contributions to Cloud Manufacturing

Cloud Manufacturing is still a new concept. Yet, studies of distributed manufacturing, collaborative manufacturing and virtual enterprise have given rise to new technologies that are capable of supporting Cloud Manufacturing. The rest of this section discusses some of these research works.

1.2.7 Service-Oriented Manufacturing Environment

Brecher et al. proposed a module-based, configurable manufacturing platform based on Service-Oriented Architecture (SOA). In this system, (called open Computer-Based Manufacturing (openCBM) environment [28]), software tools

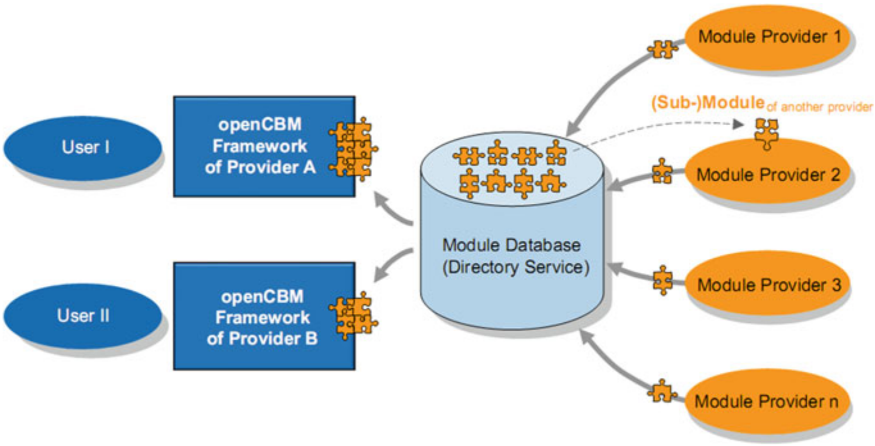

Fig. 1.4 OpenCBM working environment [28]

along the CAD-CAM-CNC chain are integrated and harmonized (Fig. 1.4). To implement the architecture and integrate inspection tasks into a sequence of machining operations, STEP standards are utilized to preserve the results of manufacturing processes that are fed back to the process planning stage [29]. The openCBM platform is organized through service-orient architecture providing the abstraction and tools to model the information and connect the models. It is much like the Platform as a Service concept that is delivered to the end user directly at the Application Layer. The service provider is deployed at the Manufacturing Resource Layer. The service is ready to be organized at the Global Service Layer.

Li et al. [30] introduced a four-layer application service integration platform that is able to bridge multiple clouds and intra-IS (Information Systems). Interactions across organization boundaries are supported by collaboration point, which plays as an interface providing data exchange, command transferring, monitoring and so forth. Implemented in a small metal product manufacturer, the system integrated manufacturing business processes with the help of collaboration agents. This research work examined the possibility of integrating existing manufacturing applications in the Cloud Computing environment.

Wang and Xu proposed a Distributed Interoperable Manufacturing Platform (DIMP) as an integrative environment among existing and future CAD/CAM/CNC applications [31, 32]. It is also based on SOA concept. In the platform, the requests and tasks from the users are modelled and collected, based on which a serial of service applications are organized and delivered back to the user. Therefore these service applications can be defined as "Virtual Service Combination", which echoes the Enterprise requirement at the Global Service Layer. Meanwhile modularized resource is effective in the Manufacturing Resource Layer of Cloud Manufacturing. Moreover, both STEP and STEP-NC data models are utilized as the central data schema. With "coupling" technologies, STEP and STEP-NC data models can be connected to commercial CAD/CAM software suites, giving the system much needed portability in the storage domain.

1.2.8 System Providing IaaS

Nessahi et al. [33] proposed a framework to address the incompatibility issue happening in the heterogeneous CAx environments. Much like an IaaS structure, software tools are connected to the platform through specific interfaces and act as "Plug-and-Play" applications. The integrated applications work with Intercommunication Bus, Manufacturing Data Warehouse, Manufacturing Knowledgebase as shown in Fig. 1.5 [34]. In this architecture, mobile agents are utilized to support the communication bus and CAx interfaces, while STEP is utilized as the neutral data format for different applications.

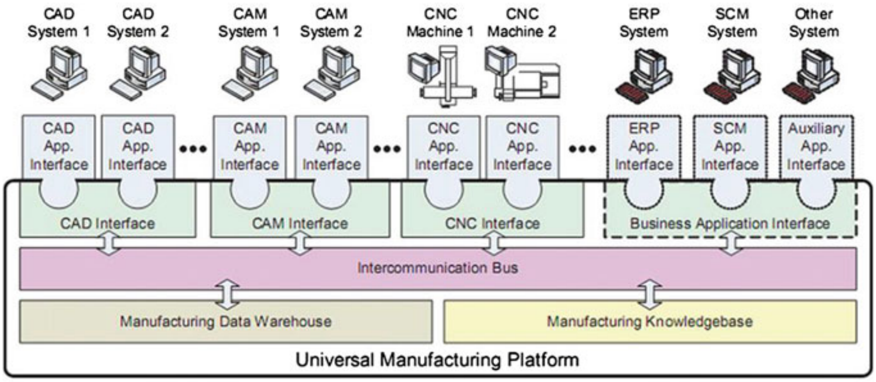

Fig. 1.5 Universal manufacturing structure

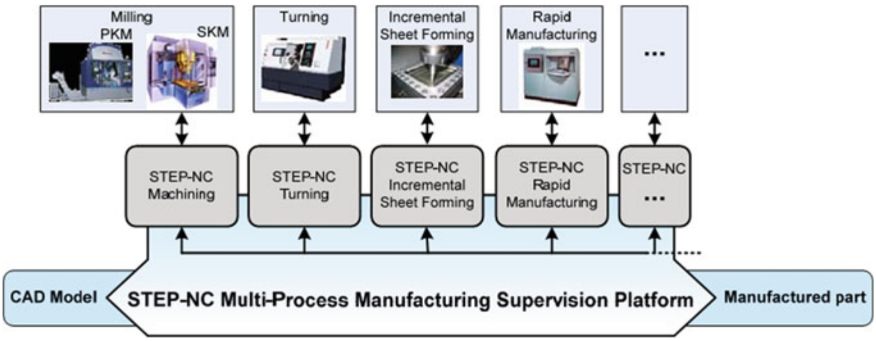

Fig. 1.6 STEP-NC multi-process manufacturing concept

More recently, Mokhtar and Houshmand [35] reported a similar manufacturing platform, combined with the axiomatic design theory to realize interoperability and production optimization. The methodology of axiomatic design is used to generate a systematic roadmap of an optimum combination of data exchange via direct (using STEP) or indirect (using bidirectional interfaces) solutions in the CAx environment. This research work provides some insight into how the manufacturing resources (Device and Software tools) can be described and encapsulated, and how the resources can be utilized and organized at the Global Service Layer.

Laguionie et al. [36, 37], studied a manufacturing system that can integrate a multi-process numerical chain. This system is called STEP-NC Platform for Advanced and Intelligent Manufacturing (SPAIM). Manufacturing processes are connected in the system through a standardized data exchanging carrier, i.e. STEP-NC (Fig. 1.6). The figure shows how the manufacturing progresses can be

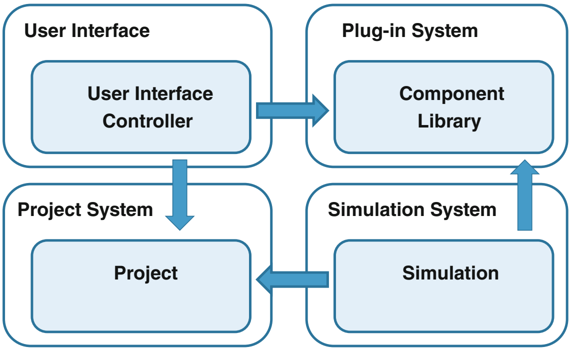

Fig. 1.7 Main elements of the plug-and-play framework

integrated via a neutral data format and how the process-planning to manufacturing procedure may be organized at the IaaS level.

1.2.9 Modularized Simulation SaaS

To achieve a run-time configurable integration environment for engineering simulations, van der Velde [38] reported a plug-and-play framework for the construction of modular simulation software. In this framework (Fig. 1.7), the user (at the Application Layer as in a Cloud Manufacturing system) is allowed to select a target of simulation and assign the performer of the simulation called "component" before running the selected components. These components are effectively software entities (or otherwise known as SaaS as in Cloud Computing/Manufacturing). They are modularized, self-contained, mobile and pluggable. After the simulation, the output is post-processed through the components. In such architecture, software modules are detected, loaded and used at run-time with the framework (i.e. the Global Service Layer) needing no prior knowledge of the type and availability of components, thus providing true plug-and-play capabilities.

Lee et al. proposed a Web-based simulation system using a neutral schema. In this approach, vender-independent data model is designed to support an interoperable simulation environment coordinating multiple simulation applications. In this four-layer architecture, interfaces are developed to interact with specific simulation applications, which receive simulation models automatically generated via a Web service layer. Thus, commercial simulation tools meshed with interfaces can work collaboratively in a distributed environment.

So far, there is no system that can facilitate a complete Cloud Manufacturing environment. A possible solution may be that of bridging the existing advanced manufacturing models with a Cloud Computing environment. In the next section, a cloud-based manufacturing system is proposed based on the previous research work.

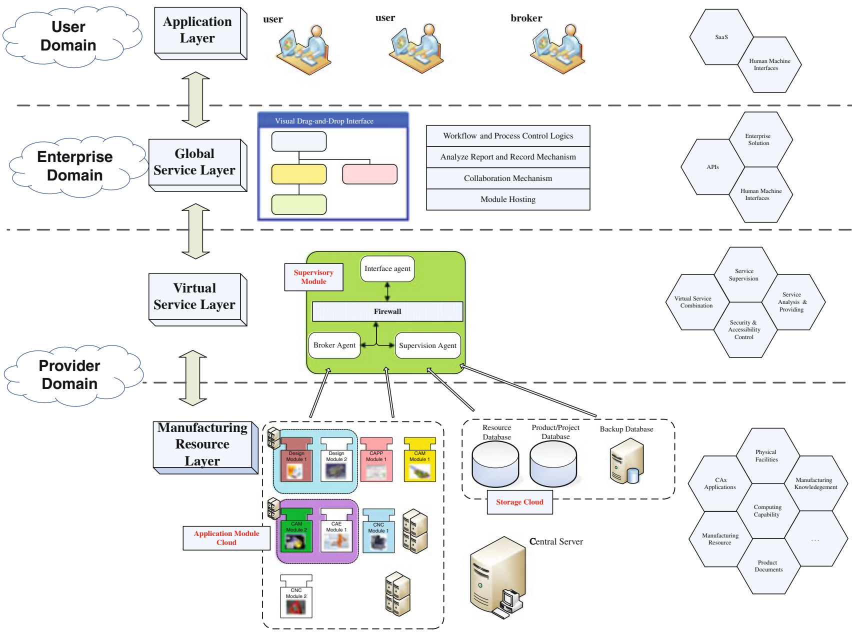

Fig. 1.8 Interoperable Cloud Manufacturing System

1.3 An Interoperable Cloud-Based Manufacturing System

As mentioned above, Cloud Manufacturing provides more opportunities and avenues to business. Moving from production-centric manufacturing to service-oriented solution, the authors propose an interoperable manufacturing environment called ICMS, which adopts Cloud Manufacturing concept (Fig. 1.8). In this section, the ICMS structure is discussed in details, which is followed by initial case studies.

1.3.1 Manufacturing Resource Layer

As discussed above, both physical manufacturing resource, e.g. devices, machines, sensors, materials, and the unphysical capabilities e.g. product documents, data and software need to be included in the cloud. In ICMS, the manufacturing capabilities are modularized as "Virtual Function Blocks (VFBs)" [32] and applied to the Manufacturing Resource Layer.

1.3.2 Module Application Cloud

With the help of VFBs, the manufacturing capabilities, including software tools (e.g. CAx applications) and hardware devices, are packaged by mobile agents as self-contained modules. Defined initially, these applications will be launched to complete the task requested by the user. Allocated by the control central, these VFBs can be easily controlled by manipulating the in-and-out data/event flow. In short, these individual VFBs can work autonomously and be considered as "black boxes". If there is any update or modification to the capability itself, the algorism of the wrapper agent can be adjusted accordingly, keeping VFB autonomous.

In particular, production machines can be represented and integrated as VFBs as well. Upon a user inquiry into machining task details, the requirement package is sent to the service provider. Then, the provider responds with appropriate machining progress plan. In this case, the input is the product documents (data-in) and materials (event-in), while the output is the machined product (event-out) and updated product data.

1.3.3 Storage Cloud

In the Storage Cloud, all the product documents, standards, intelligent properties, and etc., are stored in remote databases. To provide an advanced mechanism to feed the right amount of data for a specific service domain, a data-exchanging environment is proposed to support the Storage Cloud [39]. Besides the product information, the manufacturing resource data is kept in the data base as well. A quantifiable resource description model is utilized to describe the functionality type, so that both the provider and user are able to choose the best module to finish a specific process. In addition, the capability and availability of machine/device is kept in the data base. In this way, the service provider is able to maintain an agile service to the user's request, with trust-worthy facilities and solutions.

To model the products and related manufacturing resources, STEP/STEP-NC is chosen as the main data format. As mentioned above, STEP/STEP-NC provides specific APs for specific applications, activities or environments, and these APs are built on the same Integrated Resource. Thus, the portability and longevity of the data is guaranteed. In Storage Cloud, a backup database is in place too, saving dynamic data timely in case of data loosing and emergent request during high traffic.

To recap, the Manufacturing Resource layer provides both physical and intellectual manufacturing capabilities. Both software packages and hardware devices are meshed as autonomous modules and implemented in the cloud. The utility of standardized product/resource format maximizes the portability of manufacturing document, and guarantees a smooth data flow. Additionally, a central server is

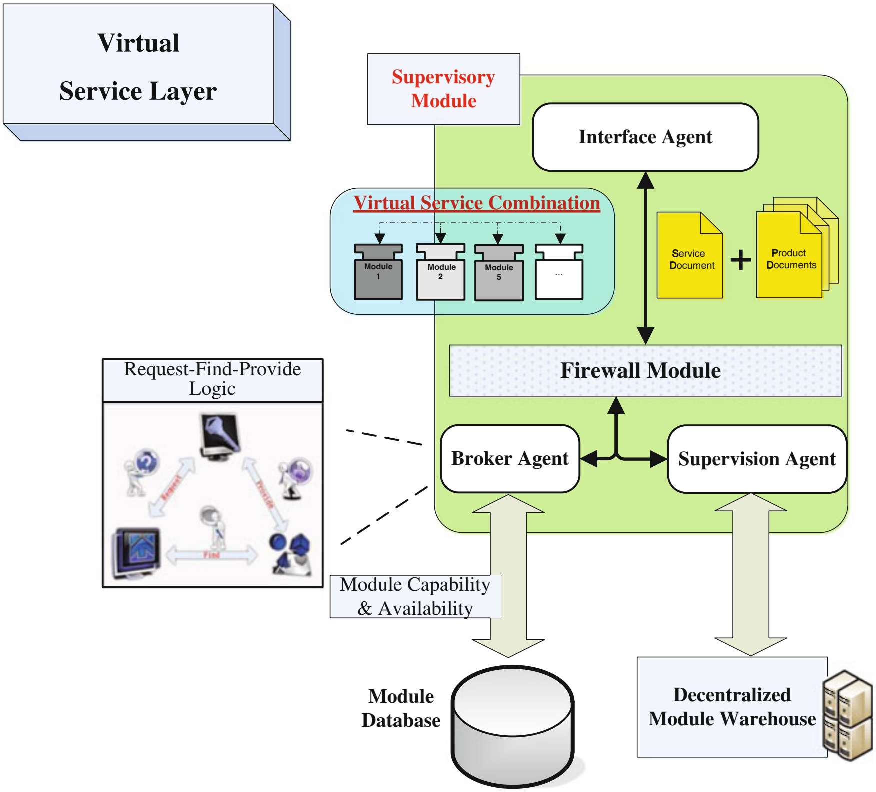

Fig. 1.9 Virtual service layer

placed at this layer providing the computing capability for the Supervisory Module on the Virtual Service Layer.

1.3.4 Virtual Service Layer

As the core of the Virtual Service Layer, the Supervisory Module plays the role of a coordinator of the service procedures. Consisting of Interface Agent, Broker Agent, Supervision Agent and Fire wall, Supervisory Module bridges service providers and users (Fig. 1.9).

The Interface Agent provides a Human Machine Interface (HMI). A service-request interface is developed to handle the service information required by the user. The service description is organized in a standard document, which is compliant with the format in the Module Database, and then sent to the Broker Agent.

Based on this service document, the Broker Agent analyses the user's demand which is mapped to the Module description data stored in the Resource Database. If there is no specific module allocation from the user, the broker agent advises with an optimistic option to fulfil the user's need and generate a complete document containing the service/application details. The Broker Agent's procedure of can be understood as "Request Find and Provide". Before the service document is sent back to the user, the capability and availability of resource will be verified by the agent. If negotiation is needed (e.g. waiting for the machine availability or modifying the plan), broker feeds the result back to the user and asks for alternative solution.

After the service document is approved by the user, the Supervision Agent organizes the related Modules in the warehouse and merges them as a "Virtual Service Combination". Thanks to the VFB concept, the software/hardware tools are easily controlled and monitored. The service is delivered to the user based on the task list defined in the service document. Supervision Agent is able to easily launch/shutdown the service by controlling the event flow of VFB. After a user finishes a task on one module, the Supervision Agent detects the event-out and delivered the module that the user may need next. Besides the role as the central serve controller, the Supervisory Agent also contains a pricing mechanism. As mentioned previously, different algorisms can be deployed based on the type of service requested. For instance, "pay-as-you-go" principle can be applied for the cloud storage service based on the amount of data user/enterprise archiving, while credit authorization/advance payment can be request by the user for reasons such as precious material preparations.

As one of the major considerations of cloud technology, Firewall Module is used for the security of user's, providers, and ICMS itself. The functionality of Firewall Module includes Identity, Protection and Privacy.

- Identity management is needed for both users and providers, by setting up different authorization levels, the participant would access different sets of data documented in the Storage Cloud, and the applications in the warehouse. For instance, the service provider is able to modify and update the software/device configuration implemented in the cloud, while the end-user can only work with the application in his working domain. When it comes to an Enterprise customer, the company will manage a privilege regime such as being able to set up the infrastructure partially at the Global Service Lever.
- For protection, the firewall takes care of both data security and the hardware protection. The Firewall agent guarantees the safety of data/software codes without leaking, and the hardware devices can only be accessed by people with the approved identity. For manufacturing industry, remote controlling scenario needs to be protected properly. Before a remote service is launched, for instance web-based machining, it has to be confirmed by both Identity management module from the Firewall and the availability message from the on-site provider.
- Privacy refers to both the critical information and the operation records. ICMS firewall protects the confidential data (e.g. credit card information, contract and personal details) from unauthorized access. Meanwhile, the activity of the user/provider working with the system cannot be collected or utilized by any unauthorized third-party.

Through Firewall, the Virtual Service Combination is delivered to the Interface Agent where the user is able to manipulate the application. For different types of users, ICMS provides Global Service for the Enterprise customer and Application Layer for end users.

1.3.5 Global Service Layer

For the Enterprise solution, the virtual Service is virtualized by the Drag-and-Drop interface. The Enterprise administrator is capable of organizing service and processes via graphical tools. The results defined by graphical flow charts are mapped to the service documents and delivered to the control kernel. In this way, an enterprise user with the accessibility is enabled to query the service easily. If there is any modification applied to the service plan, the result affects the service document before it is fed back to the virtual service layer.

At this layer, workflow and process control logic is in place to meet the enterprise's need of management. The enterprise administrator has the authority of launching, changing, or terminating a service or procedure, which provides full flexibility to the customer. Report, record and diagnose mechanisms provide the records and analysis of service operations. For manufacturing industry, collaborative design/process planning is commonly required. In ICMS the collaboration mechanism is supported by standardized process/resource document with novel data collecting/archiving method mentioned earlier. After processed by the applications, the latest data are kept in the Storage Cloud with previous versions saved in the Backup Database. Therefore the data traceability and reliability is guaranteed. APIs can be provided at this layer too. Thus, the user can connect ICMS applications to their existing applications.

1.3.6 Application Layer

At this layer, interface is provided between the user and ICMS. It provides both graphical service and virtual working environment. Firstly, the user is identified by the Firewall. After the identity is confirmed, the user is asked about what kind of service he or she requires. Based on the user's description, the information is kept in the initial service document and sent to the Broker Agent at the Manufacturing Resource Layer. The Brokered Agent scans the service document and maps the descriptions to the available module function. After the module(s) fulfilling the inquiry is (are) chosen by the Broker Agent, an updated service document will then be sent back to the user for confirmation. After approved by the user, the Supervision Agent packages the modules as a "Virtual Service Combination" and provides the service in the virtual manufacturing environment. Controlled by the Firewall, the user can only retrieve the resource he/she is authorized to, without

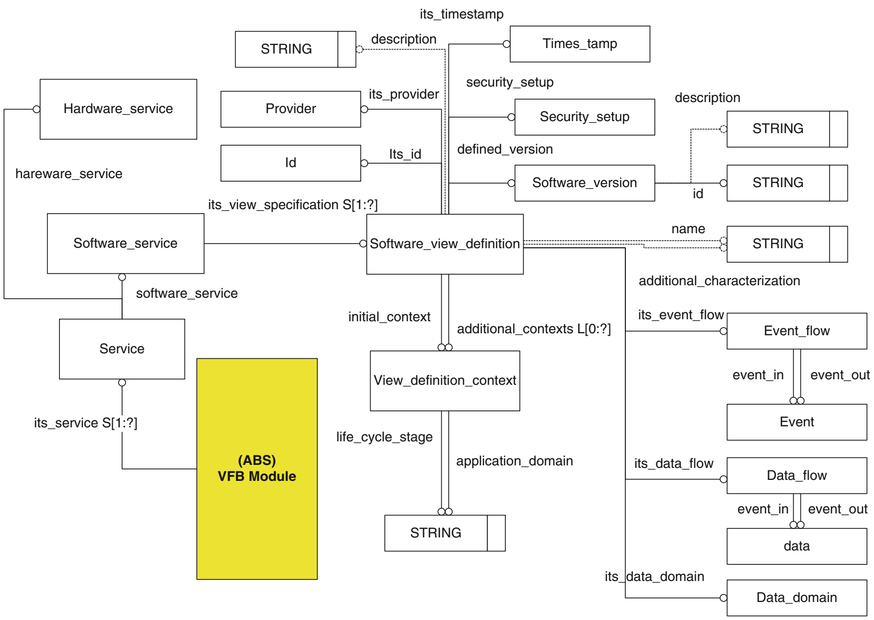

Fig. 1.10 VFB module

disturbing others' working domain. For specific physical devices such as machines and robots, exclusive agreement applies, which means no other user is able to access this device or make changes while it is occupied.

To present the service information of VFBs, data models are in need to describe such information. Even though ISO10303 part 1746 [40] provides data structures describing information product (software), more information is required. Figure 1.10 shows a VFB data model Express-G [41].

The top-level of VFB has its_service entity to describe the service that VFB can offer at the functionality level. Note that one single VFB could have multiple specifications or software/hardware applications integrated across the system. Thus, both multi-functionality and reusability are guaranteed in ICMS. In this figure, software service is chosen as example. The detailed service information is defined through Software_view_definition and its attributes its_id, its_provider, description, defined_verstion, initial_context, additional_context, its_time_stamp, name, additional characterization, its_event_flow and its_data_flow.

Entity Id stores identity information for every single service so that service can be tagged easily. Working with the Software_version, Id enables the full traceability of service and version history of a VFB.

Entity Provider describes the provider description of a service. Via this entity, the detailed specification about the provider can be easily found and utilized. The system administrator is enabled to setup the authority rules accordingly. Meanwhile the user can get more information about potential business partners during survey.

Entity Security_setup defines the data representing the security level and authorization information, which is to be processed through Firewall. After the user is identified, the firewall is able to manage the authorization process based on the result of comparing the VFB security configuration with the user privilege domain.

Entity View_definition_context stored the technical definition about the service a VFB provides. Through further definition of application_domain and life_-cycle_stage, the scope of a software tool can be defined in details. In this entity, multi-definition is available as well realized by additional context. Supplementary description of complex functionality of integrated software can be modelled without information lost.

Entity Event describes the attributes event_in and event_out which support the event-driven concept of VFB. Entity data_flow defines the input and output data of each service. A copy of the input data is saved and linked to attribute data_in after the service is initialized while an output copy is saved after the service terminates. Entity Event_flow and Data_flow are defined in a familiar structure as they are in the Service Document, where the event-trigger input/output information is stored. With this familiar definition, communications between Supervisory Module and VFB warehouse are streamlined. Thanks to these interfaces, Broker Agent is enabled to access the Resource Database directly and make an optimal selection with the information gathered here.

As mentioned before, ICMS provides mechanisms feeding the right amount of data for a specific working domain. Entity Data_domain defines and records both the relationships between entities within a data-subset that a service is working with, and the connections around the subset. Based on the service description, the information request asked by the user will be tagged and extracted based on the type of connections. More detailed explanation of this mechanism is given in [39].

Entity Time_stamp records the time when the service is commenced and terminated. With the attribute date_and_time which is defined in ISO 10303-41 [42], history of service and project can be traced from the chronological data.

Attribute description offers more detailed software profile in a flexible form. The provider is able to add more detailed introduction/description of the software application, while the user is able to record the experience, comments and feedback after terminating the service.

As mentioned above, metering and fee-calculating mechanism works with activities at this layer directly. Consumptions such as electricity, material, gas and storage place (including physical and data storage) are monitored and metered by the Supervisory Module. It can be understood as SaaS structure deployed at this layer. User Identity procedure is in place after the user connects to the system.

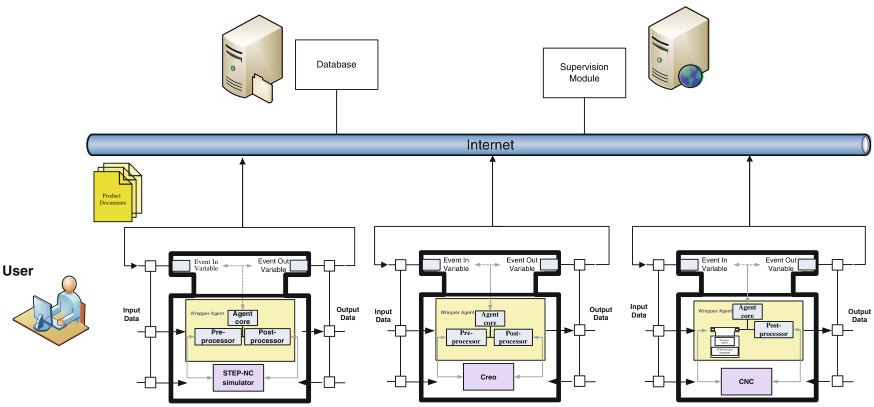

Fig. 1.11 VFB service integration

1.4 Case Study

To evaluate VFB and its service integration philosophy, a case study has been carried out. As illustrated in Fig. 1.11, software tools and CNC machines are packed and integrated as a Virtual Service Combination. Based on the Service Document delivered by the Supervisory Module, the STEP-NC simulator, Creo and CNC application are launched for the user one after another to fulfil his/her request. Using Java Agent programme, VFBs wrap these applications by controlling the event/data flow. For example, when the user finishes with STEP-NC simulator and saves the file (Data-Out) in the database, this action is defined as "Even-Out" for this VFB and triggers its VFB's algorithm. The Wrapper agent inside VFB shuts down the application and feeds back the service progress to the Supervision Module. After the Supervision Module sends back the next command line based on the service document, the next VFB, which is the Creo module, is launched, and then the agents keep listening to the user activity until the next trigger event comes along. In this way, the applications are easily controlled and integrated in the cloud.

When a VFB is initially defined in the application cloud, a description document is generated in the Resource Database. By using the data structure compliant with STEP standard, data portability between VFB resources and serve document are realized. Thus the Supervision Module is capable of searching and choosing appropriate VFB solutions by mapping the user's request to the VFB database.

In particular, one VFB can be employed as a pre-/post-processor within another VFB. Referring to the IEC standard [43], when a VFB algorithm and the control of its execution are expressed entirely in terms of interconnected VFB, the structure is called composite VFB. In this case study, it is assumed that the CNC machine cannot take STEP-NC data format naturally. Hence a STEP-NC/CMC interpreter is allocated to interpret STEP-NC file into machine command code before it is sent

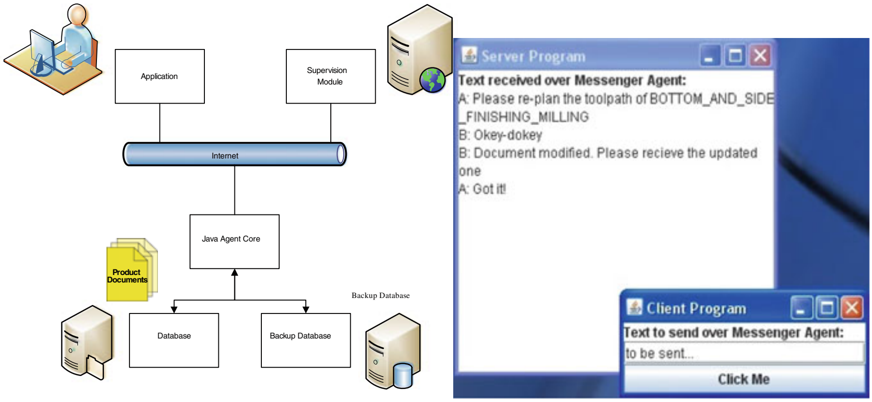

Fig. 1.12 Data transmission and web-based messenger

to the CNC application. This shows that integration of applications using VFBs guarantees the mobility and re-usability of manufacturing resources.

In addition, the Web-based communication structure is built for ICMS (Fig. 1.12). Socket-server connection bridges the user's device and Central Server. User with accessibility is able to extract documents from the database remotely over the Internet and archive it afterwards. The transmission speed is affected by the network traffic, which reached 2 MB/s during the implementation test. Thanks to the mobility of Java language, the system can be easily implemented in different operating environments.

Moreover, a real-time text-based message system is also developed. For communication between a user and a provider, or the collaborative work amongst participants, the system provides a messenger module enabling the users to send simplified data or message over the Internet. The users are enabled to build point-to-point real-time communication through the interface with the ICMS infrastructure.

1.5 Conclusions

Cloud Computing brings new opportunities and possibilities to manufacturing industry. In the competitive market environment, enterprises can reap a multitude of benefits from implementing the cloud concept into their businesses. In this chapter the authors reviewed the Cloud Computing technologies and the related manufacturing research. By using cloud, the Manufacturing Resource Management, Enterprise Management and Information Management can be greatly enhanced.

In the second half of this chapter, the authors proposed a cloud-based system, namely ICMS. In this service-centric system, business processes are modelled by a standardized service document, which is mapped to manufacturing resources and modularized in the application cloud. Thus, customized needs are fulfilled by a service-centric approach with the help of interacting between service supervision and resource integration.

The system provides an interoperable environment integrating not only software tools but also physical manufacturing devices in form of VFBs. Thus, manufacturing resources are merged as Virtual Service Combinations according to the user's original request. The reusability of VFBs can help both user and provider to realize a task solution efficiently. Moreover, vender-independent data models are deployed to improve the accessibility of the manufacturing resources and product/project documents. Besides the native file formats of applications, STEP/STEP-NC formats provide more portability, longevity and visibility performance. In a Cloud perspective, these data models enable an information exchange environment without additional time-/cost-consuming tasks.

Cloud technologies provide the opportunity to re-shape manufacturing businesses. They provide more flexibility and interactivity between users and providers. ICMS is suitable for such a globalized and decentralized environment. Standardized resource integration and service modelization help implement existing and future applications in the Cloud Manufacturing environment.

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Chapter 2
A Distributed Service of Selective Disassembly Planning for Waste Electrical and Electronic Equipment with Case Studies on Liquid Crystal Display

Weidong Li, K. Xia, B. Lu, K. M. Chao, L. Gao and J. X. Yang

Abstract Waste Electrical and Electronic Equipment (WEEE) are one of the most significant waste streams in modern societies. In the past decade, disassembly of WEEE to support remanufacturing and recycling has been growingly adopted by industries. With the increasing customization and diversity of Electrical and Electronic Equipment (EEE) and more complex assembly processes, full disassembly of WEEE is rarely an ideal solution due to high disassembly cost. Selective disassembly, which prioritizes operations for partial disassembly according to the legislative and economic considerations of specific stakeholders, is becoming an important yet still challenging research topic in recent years. In this chapter, a Particle Swarm Optimization (PSO)-based selective disassembly planning method embedded with customizable decision-making models and a novel generic constraint handling algorithm has been developed. With multi-criteria decision

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making models, the developed method is flexible to handle WEEE to meet the various requirements of stakeholders. Based on the generic constraint handling and intelligent optimization algorithms, the research is capable to process complex constraints and achieve optimized selective plans. Practical cases on Liquid Crystal Display (LCD) televisions have been used to verify and demonstrate the effectiveness of the research in different application scenarios. A distributed environment to deploy the service for remote access and control has been designed to support collaborative work.

2.1 Introduction

The mounting demand for new products has brought more production activities worldwide in recent years. This rapid development, however, has been hindered by the increasing concerns on the scarcity of natural resources and environmental issues. Statistics show that from 1985 the resource consumption on the global level has been higher than the ecological capability of the Earth. It has been estimated that the required bio-capacity of two Earths is necessary to satisfy the need of the development in 2050 according to current production and consumption trends [1]. On the other hand, more and more products after services are filled up in landfills. Among them, Electrical and Electronic Equipment (EEE) after services, that is, Waste Electrical and Electronic Equipment (WEEE), are becoming one of the major and challenging waste streams in terms of quantity and toxicity. For instance, there are approximately 7 million tons of WEEE generated in Europe per year [2]. In China, 1.1 million tons of WEEE are generated per year [3]. Due to the rapid technical innovations and shorter usage lifecycle of EEE, WEEE are growing much faster than any other municipal waste streams. To keep the Earth cleaner, End-of-Life (EoL) recovery strategies are critical to shape the future of WEEE lifecycle management patterns. Among the strategies, remanufacturing is viewed as a “hidden green giant” and attracting escalating attentions of researchers and practitioners [4–7]. Remanufacturers seek to bring some components of products after their services back into ‘as new’ condition by carrying out necessary disassembly, overhaul, and/or repairing operations for re-use to extend lifecycles. There are two driving forces for industries in adopting the relevant technologies and practices, i.e., stricter legislative pressure for environmental protection and better profit margins from remanufacturing. The explanations are expanded below.

- The WEEE Directive has been enacted and implemented from 2003 in Europe, and the equivalent Directives have been developed in different countries of the world. Further proposals for the tighter WEEE Directives have been suggested to regulation bodies with an aim to make products and components after services more recyclable, reusable and remanufacturable (i.e., reducing the waste arising from WEEE, improving and maximizing recycling, reuse and other forms of recovery of waste from WEEE, and minimizing the impact on the environment from their treatment and disposal);

- According to the WEEE Directives, a producer (manufacturer, brand owner or importer)'s responsibility is extended to the post-consumer stage of WEEE, instead of stopping at selling and maintenance (i.e., Extended Producer Responsibility—EPR [8, 9]. The EPR is aimed at encouraging producers especially manufacturers to provide cradle-to-grave support to reduce environmental impacts, such that they work closely with remanufacturing industries to recover maximum values and reduce environmental toxicity/hazardousness. For instance, the remanufacturing legislative initiatives are underway in the EU and USA to ensure Original Equipment Manufacturers (OEMs) and suppliers to provide free access to remanufacturing information facilities in global chains [10];
- Good remanufacturing planning and management can effectively balance economic and environmental targets, and bridge gaps between the shorter innovation cycles of EEE and the extended lives of components of WEEE. Remanufacturing industries in the EU and worldwide have been recently growing quickly because of better economic return values. There are numbers of successful cases in industries, including single use cameras (Eastman Kodak and Fuji Film), toner cartridges (Xerox), personal computers (IBM, HP, Toshiba, Reuse network-Germany), photocopiers (Fuji Xerox—Australia, Netherlands and UK), commercial cleaning equipment (Electrolux), washing machines (ENVIE—France), mobile phones (Nokia, ReCelluar—USA, Greener solution—UK).

Disassembly planning, which is used to determine sensible disassembly operations and sequencing, is critical in remanufacturing. Effective disassembly planning can significantly improve the recycling and reuse rates of components and materials from WEEE to ensure maximum value recovery. For a set of WEEE, there could be a number of different sequences of disassembly operations constrained technically and geometrically between the components of the WEEE, leading to different decision-making models according to the perspectives and criteria of stakeholders [11]. As thus, it becomes difficult for remanufacturers to solely depend upon their experiences to plan disassembly operations so as to recover a larger proportion of components and fulfill environmental targets at a reasonable cost. In the past years, research has been carried out to address the issues of disassembly. The previous research can be generally summarized as the following two categories:

- Disassembly for design. Disassembly approaches for EEE such as consumer electronic products have been developed to use smart materials like Shape Memory Polymers (SMPs) in the design of embedded releasable fasteners to facilitate the disassembly processes of the products [12–17]. Design for remanufacturing/disassembly principles have been spread among Japanese manufacturers since products with the principles are more profitable in this context than those that were not designed with this purpose [5, 18, 19];

- Disassembly planning and operation sequencing. Typical disassembly operations based on manual, semi-automatic and automatic processes and the associated tool-kits were summarized [5]. Based on disassembly operations and the precedence constraint relationships among the disassembly operations, sequencing rules and intelligent and/or meta-heuristic reasoning algorithms were applied to deduce an optimal plan from a large pool of candidate solutions [11, 20–22]. In recent years, remanufacturers are facing many challenges to disassemble WEEE due to their high customization and diversity, high integration level, and more complex assembly processes. Current economic analyses have demonstrated that full disassembly is rarely an optimal solution and necessary owing to high disassembly cost. *Selective disassembly*, *which prioritizes operations to implement partial dismantling of WEEE so as to take account of the legislative and economic considerations and meet the specific requirements of stakeholders*, *is a promising alternative and has therefore become a new research trend* [5, 23, 24].

Attributing to booming personalized and mass-customized EEE, it is still challenging to apply the developed methods to the increasingly diversified and personalized WEEE to make sensible decisions and meet different stakeholders' perspectives. In this chapter, a Particle Swarm Optimization (PSO)-based selective disassembly planning method with customizable decision making models and a novel constraint handling algorithm has been developed. The method is adaptive to various types of WEEE, flexible for customized decision modeling and making for different stakeholders, and capable for handling complex constraints and achieving optimized solutions during disassembly planning. Industrial cases on Liquid Crystal Display (LCD) televisions have been used to verify and demonstrate the effectiveness of the developed method in different application scenarios.

2.2 Selective Disassembly Planning Approach

2.2.1 Customizable Decision-Making Modeling for Selective Disassembly Planning

Disassembly of WEEE involves different stakeholders, such as environmental regulators and remanufacturers, which will lead develop different decision-making models. For instance, according to the WEEE Directive, WEEE regulators will check whether remanufacturing companies are able to recycle at least 75 % of WEEE by weight and remove/recover all the hazardous materials. In other words, at least 75 % of WEEE are required to be dismantled to a component level, and all the components containing hazardous materials need to be taken apart from WEEE for further recycling and processing. Apart from fulfilling these fundamental environmental targets, remanufacturers would also improve the economic efficiency by prioritizing valued components during disassembly. In Fig. 2.1, an example of LCD WEEE is used to illustrate the above scenario.

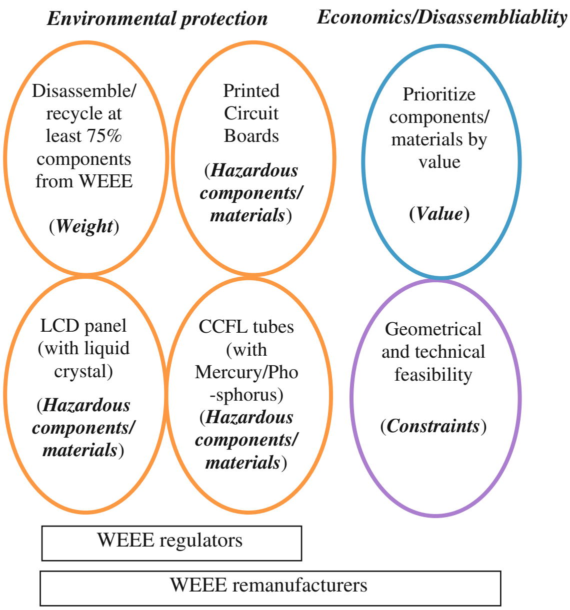


Fig. 2.1 Criteria for different decision-making models

In order to develop a selective disassembly planning method that is suitable for stakeholders to process various types of WEEE and meet their specific requirements, it is imperative to define customizable decision-making models. The models (Disassembly indices and Objective) developed in this research are described below.

2.2.1.1 Disassembly Indices

In the following formulas, two symbols will be used frequently and they are explained here first.

n	The number of the total disassembly operations in a plan of a set of WEEE
m	The number of the disassembly operations in a selective disassembly plan
$Position(Oper(i))$	The position (sequence) of the ith disassembly operation in a disassembly plan

- *Selective Disassembly Plan* (*DP*) *and Disassembly Operation* $(Oper(i))$

A set of WEEE can be fully disassembled using a disassembly plan. The number of all the operations in the plan is n. A Selective Disassembly Plan (*DP*), which consists of a set of disassembly operations, which is a part of the above complete operations. The number of the selected operations is m, and the *ith* operation is denoted as $Oper(i)$. *DP* can be represented as:

$$DP = \bigcup_{i=1}^{m} (Oper(i), Position(Oper(i))) \quad (2.1)$$

where $\bigcup$ represents the set of disassembly operations, and $m \leq n$.

For instance, there are a set of disassembly operations $Oper(1), Oper(2), Oper(3), Oper(4)$, and their positions in *DP* are 4, 2, 1, 3 (e.g., $Position(Oper(1)) = 4$), so that the sequence of the operations in *DP* is $Oper(3), Oper(2), Oper(4), Oper(1)$.

Meanwhile, $Oper(i)$ has some properties related to the environmental and economic targets defined as follows.

- *Hazardousness* $(H(Oper(i)))$ *and Hazardousness Index* $(Index\_H)$

Hazardousness of the *ith* disassembly operation is to indicate the level of hazardousness contained in the component(s) removed by the operation from the WEEE. It can be represented in a qualitative means, i.e., high, relatively high, medium, and low, and converted to a quantitative means accordingly, such as (5, 3, 1, 0) for (high, relatively high, medium, low). *Index_H* of a set of WEEE is to indicate the accumulated hazardousness contained in the component(s) removed by the disassembly operations in the WEEE. *Index_H* can be computed as below:

$$Index\_H = \sum_{i=1}^{m} (H(Oper(i)) * Position(Oper(i))) \quad (2.2)$$

A smaller *Index_H* will be beneficial. The function of multiplying $H(Oper(i))$ and its position $Position(Oper(i))$ in *DP* is to ensure that the disassembly operations with higher hazardousness (i.e., $H(Oper(i))$) are arranged in earlier positions in *DP* to achieve a smaller *Index_H*.

For instance, the hazardousness of $Oper(1), Oper(2), Oper(3), Oper(4)$ are (high, low, medium, relatively high) respectively, which can be converted to (5, 0, 1, 3). The positions of the operations in *DP* are (4, 2, 1, 3). Therefore, the hazardousness index of *DP* is (5 * 4 + 0 * 2 + 1 * 1 + 3 * 3) = 30. If the positions of the operations are re-arranged as (1, 4, 3, 2), then the hazardousness index is (5 * 1 + 0 * 4 + 1 * 3 + 3 * 2) = 14. The latter is lower than the earlier since the operations with higher hazardousness are arranged earlier in the latter. In Objective defined later on, a weighted minimum hazardousness index will be pursued to ensure the operations to remove the most hazardous components will be arranged as early as possible to improve the efficiency of hazardousness removal in a selective disassembly plan.

- *Potential Recovery Value* $(V(Oper(i)))$, *Disassembly Time* $(T(Oper(i)))$ *and Potential Value Index* $(Index\_V)$

$V(Oper(i))$ of the *ith* disassembly operation is to indicate the potential recovery value of the component(s) disassembled from the WEEE by the operation. The disassembled component(s) could be re-usable so that $V(Oper(i))$ can be represented as the depreciation value of the equivalent new component(s). $T(Oper(i))$ represents the time spent for the disassembly operation $Oper(i)$. *Index_V* of a set of WEEE is to indicate the accumulated potential value index by the disassembly operations in the WEEE. *Index_V* can be computed as below:

$$Index\_V = \sum_{i=1}^{m} ((V(Oper(i))/T(Oper(i)) * Position(Oper(i))) \tag{2.3}$$

A smaller *Index_V* will be beneficial. $V(Oper(i))/T(Oper(i))$ represents the potential value recovery efficiency of $Oper(i)$. The function of multiplying $V(Oper(i))/T(Oper(i))$ and its position $Position(Oper(i))$ in *DP* is to ensure that the disassembly operations with higher $V(Oper(i)/T(Oper(i))$are arranged earlier to achieve a smaller *Index_V* so as to achieve a higher efficiency of potential value recovery for a selective disassembly plan.

- *Weight Removal* $(W(Oper(i)))$ *and Weight Removal Index* $(Index\_W)$

$W(Oper(i))$ is to indicate the level of the removed weight by the *ith* disassembly operation from the WEEE. It can be represented by the weight of the component(s) disassembled by the operation. *Index_W* of a set of WEEE is to indicate the accumulated weight removal index by the disassembly operations in the WEEE. *Index_W* can be computed as below:

$$Index\_W = \sum_{i=1}^{m} (W(Oper(i)) * Position(Oper(i))) \tag{2.4}$$

Similarly, a smaller *Index_W* will be beneficial. The function of multiplying *W*(*Oper*(*i*)) and its position *Position*(*Oper*(*i*)) in *DP* is to ensure that the disassembly operations with higher *W*(*Oper*(*i*)) are arranged earlier to achieve a smaller *Index_W* in order to improve the efficiency of weight removal in a selective disassembly plan.

2.2.1.2 Disassembly Constraints

During the process of disassembly, there are some geometrical or technical constraints to specify precedent relationships between disassembly operations. Three examples in Fig. 2.2 are used to illustrate the concept. In (a) and (b), there are two disassembly directions for Components A and B respectively. Due to the geometrical blocking relationship, the first disassembly operation (denoted as *Oper*(1)) is to disassemble the joining mechanism associated with Component B and Housing, and the second disassembly operation (*Oper*(2)) is to dismantle the joining mechanism between Components A and B. Therefore, *Oper*(1) is constrained to be prior to *Oper*(2) geometrically. In (c), there is a single disassembly direction for Components A and B. Geometrically, it can dismantle either the joining mechanism between Component B and Housing first (*Oper*(1)), or the

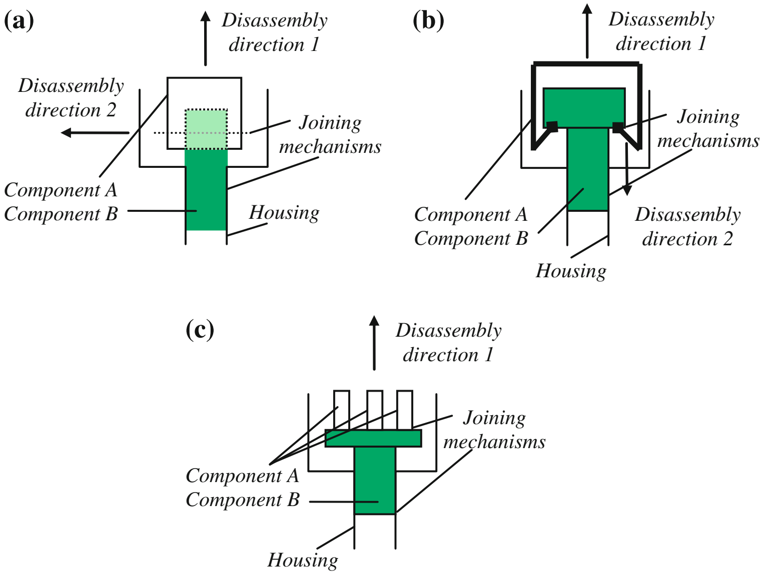


Fig. 2.2 Examples of constraints during disassembly **a** A geometrical constraint. **b** A geometrical constraint. **c** Technical constraint

joining mechanism between Components A and B first (*Oper*(2)) first. However, from the technical point of view, it is recommended to remove the joining mechanism between Component B and House first, considering that the disassembly of the second joining mechanism needs more operation space. Therefore, *Oper*(1) is constrained to be prior to *Oper*(2) technically.

2.2.1.3 Decision-Making Objective

Disassembly decision-making will be modeled as a constraint-based optimization problem. The Objective can be customized to address different requirements of stakeholders through weight setting by users. The Objective is represented below:

$$\begin{aligned} & Mimimise(Index\_H, Index\_V, Index\_W) \\ & = Minimise\left(w_1^* Index\_H + w_2^* Index\_V + w_3^* Index\_W\right) \end{aligned} \tag{2.5}$$

where $w_1 - w_3$ are the weights. Different weights can be set by different users to reflect varied priorities of the three indices. A higher weight means more attentions will be paid to that index, and a zero value means such index will not be considered. In order to rationalize the model, the three indices are required to be normalized to be in the same measurement scale. The normalization process is illustrated in case studies.

2.2.2 A Generic Constraint Handling Algorithm

There could be a number of precedence constraints between the disassembly operations for a set of WEEE. Under the situation, it is usually difficult to generate a valid disassembly plan. In order to address complex constraints in WEEE disassembly dynamically and adaptively, a new constraint handling algorithm, which employs a generic process to handle various constraints, has been developed. The manipulation operations of the algorithm, which are based on data structure and double-linked list design, can ensure that all the constraints in a disassembly plan will be met during the process of selection and optimization process (such selection and optimization process will be explained in Sect. 2.2.3). The workflow of the algorithm is described in Fig. 2.3. In the process, there are several important symbols to be highlighted below.

m	The number of the selective disassembly operations for a set of WEEE
*m*_1	The number of the disassembly operations without any constraints
m − *m*_1	The number of the disassembly operations with constraints
LL	A double linked list for the disassembly operations with constraints
*LL*_1	A double linked list to store immediate results during the algorithm manipulation
Current operation	The working operation during the manipulation of the algorithm

2.2.3 An Improved Particle Swarm Optimization Algorithm

The different selection and optimization sequencing of disassembly operations for a set of WEEE usually brings forth a large search space. Conventional algorithms are often incapable of optimizing the problem. To address it effectively, some modern optimization algorithms, such as Genetic Algorithm (GA) and Simulated Annealing (SA), have been developed to quickly identify an optimized solution in a large search space through some evolutional or heuristic strategies. In this research, an improved algorithm based on a modern intelligent algorithm, i.e., PSO, has been applied to facilitate the search process. Moreover, the improved PSO has been also compared with GA and SA for this disassembly planning problem to show the characteristics of the algorithms. More details of GA and SA implementation can refer to [25, 26].

A classic PSO algorithm was inspired by the social behavior of bird flocking and fish schooling [27]. Three aspects will be considered simultaneously when an individual fish or bird (particle) makes a decision about where to move: (1) its current

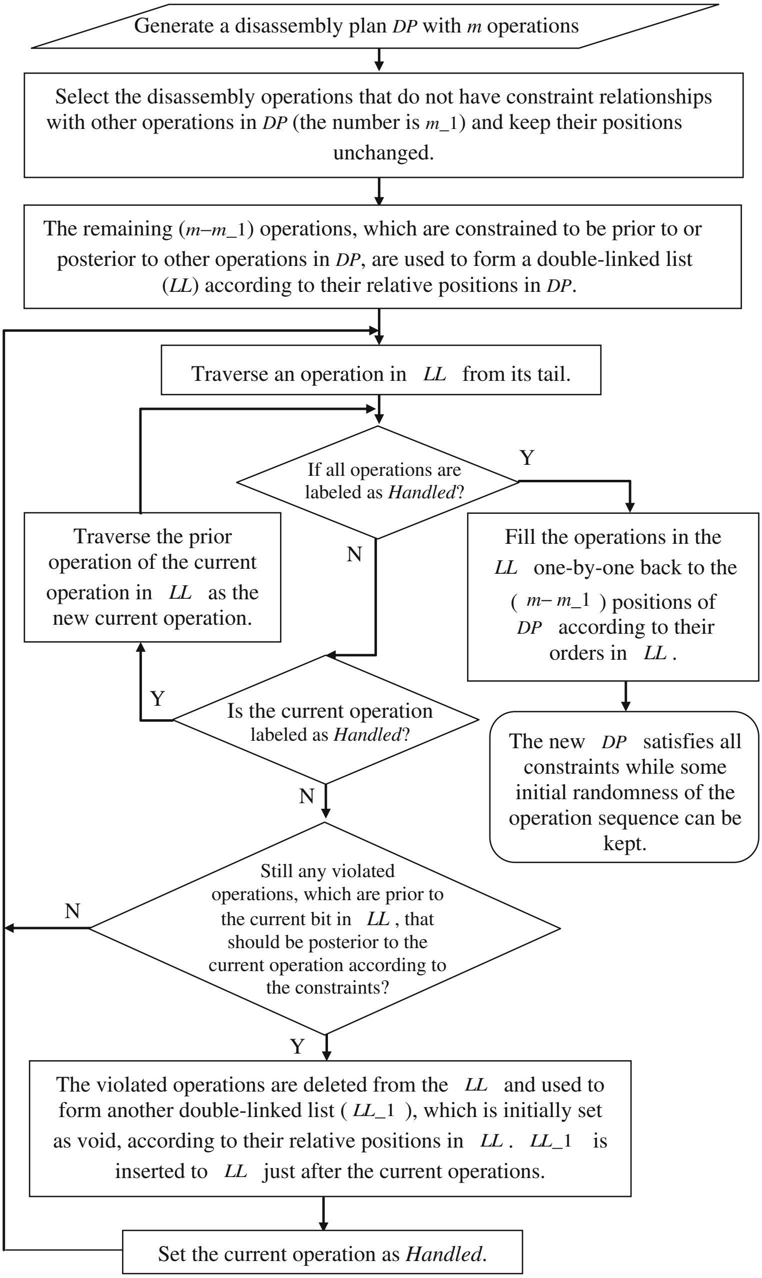


Fig. 2.3 The workflow of the generic constraint handling algorithm

moving direction (velocity) according to the inertia of the movement; (2) the best position that it has achieved so far; and (3) the best position that its neighbor particles have achieved so far. In the algorithm, the particles form a swarm and each particle can be used to represent a potential disassembly plan of a problem. In each iteration, the position and velocity of a particle can be adjusted by the algorithm that takes the above three considerations into account. After a number of iterations, the whole swarm will converge at an optimized position in the search space. A classic PSO algorithm can be applied to optimize the disassembly planning models in the following steps:

(1) Initialization

- Set the size of a swarm, e.g., the number of particles "*Swarm_Size*" and the max number of iterations "*Iter_Num*";
- Initialize all the particles (a particle is a disassembly plan *DP*) in a swarm. Calculate the corresponding indices and Objective of the particles (the result of the objective is called *fitness* here);
- Set the local best particle and the global best particle with the best fitness.

(2) Iterate the following steps until "*Iter_Num*" is reached

- For each particle in the swarm, update its velocity and position values;
- Decode the particle into a disassembly plan in terms of new position values and calculate the fitness of the particle. Update the local best particle and the global best particle if a lower fitness is achieved.

(3) Decode global best particle to get the optimized solution

However, the classic PSO algorithm introduced above is still not effective in resolving the problem. There are two major reasons for it:

- Due to the inherent mathematical operators, it is difficult for the classic PSO algorithm to consider the different arrangements of operations, and therefore the particle is unable to fully explore the entire search space;
- The classic algorithm usually works well in finding solutions at the early stage of the search process (the optimization result improves fast), but is less efficient during the final stage. Due to the loss of diversity in the population, the particles move quite slowly with low or even zero velocities and this makes it hard to reach the global best solution. Therefore, the entire swarm is prone to be trapped in a local optimum from which it is difficult to escape.

To solve these two problems and enhance the capability of the classic PSO algorithm to find the global optimum, new operations, including crossover and shift, have been developed and incorporated in an improved PSO algorithm. Some modification details are depicted below.

(1) New operators in the algorithm

- Crossover. Two particles in the swarm are chosen as Parent particles for a crossover operation. In the crossover, a cutting point is randomly determined, and each parent particle is separated as left and right parts of the cutting point. The positions and velocities of the left part of Parent 1 and the right part of Parent 2 are re-organized to form Child 1. The positions and velocities of the left part of Parent 2 and the right part of Parent 1 are re-organized to form Child 2;

- Shift. This operator is used to exchange the positions and velocities of two operations in a particle so as to change their relative positions in the particle.

(2) Escape method

- During the optimization process, if the iteration number of obtaining the same best fitness is more than 10, then the crossover and shift operations are applied to the best particle to escape from the local optima.

2.3 Case Studies for Selective Disassembly Planning

2.3.1 Background

Televisions can be generally classified into six groups: Cathode Ray Tube (CRT), LCD, Plasma Display Panel (PDP), Light Emitting Diode (LED), Rear Projection (RP) and Digital Light Projection (DLP). The LCD televisions have been developed quickly over the past decades and they are now the market leader sharing the biggest market (e.g., the global market figures for the LCD televisions are forecasted to surpass $80 Billion in 2012 [24]). A LCD television produces a black and colored image by selectively filtering a white light. The light is typically provided by a series of Cold Cathode Fluorescent Lamps (CCFLs) at the back of the screen. The LCD televisions studied here are produced by the Changhong Electronics Company, Ltd. from China, which is the biggest television producer in China. The company provides information about LCD televisions of the type of LC24F4, such as the Bill of Materials (BoMs), exploded view, mass of each parts and the detailed assembly processes. The structure of the LCD television is shown in Fig. 2.4a and b. The typical exploded view of a LCD television is shown in (c). As shown in (d), a LCD television is typically assembled by three main parts: front cover assembly part, back cover assembly part and base assembly part. Among them, the front cover assembly part is composed of a surface frame, a remote control receiver board, a control button board, a main board, a power supply board, a Low-Noise Block (LNB) converter board (optional), and a DVD ROM (optional). The mass of the LC24F4 LCD television is 5963.8 g, and the main component/material composition is shown in Fig. 2.5, in which the percentage is represented in terms of the ratio of Mass. Among the component/material composition, the Printed Circuit Boards (PCBs, which are mainly main boards and power supply boards) and LCD screens are quite complex in terms of structure and recycling. Other components/ materials include cables, wires, pins, switches and rubbers. The cables, wires, pins

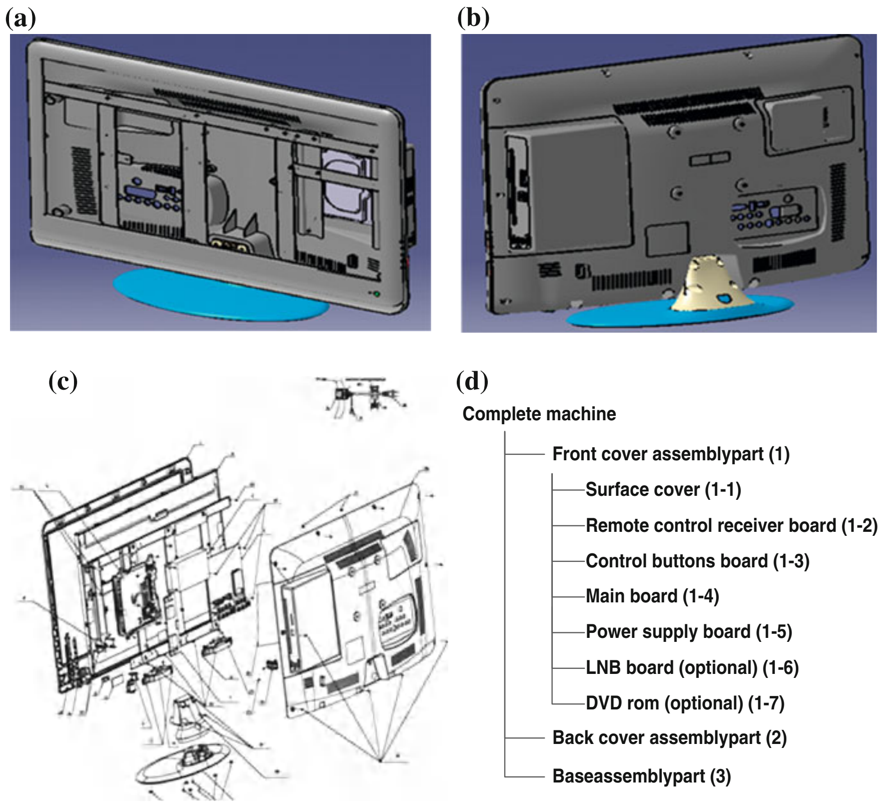
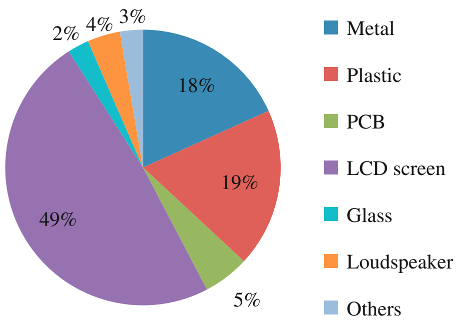


Fig. 2.4 A LCD television and its structure views. **a** Front view of the LCD television. **b** Back view of the LCD television. **c** Exploded view of the LCD television. **d** Part of the BoMs of the LCD television

Fig. 2.5 The component/material composition of the LCD television



and switches consist of plastics that are usually Polyvinyl Chloride (PVC), non-ferrous mainly Copper and Aluminum. Current EoL disposal for LCD televisions is typically landfill or incineration, and this form of disposal restricts the ability to recover potentially reusable materials from waste LCD television, e.g., components to be reused or remanufactured, and recycled materials like Steel, Aluminum, Copper, etc. Due to the increasingly significant market share of LCD televisions, it is imperative to apply effective methods to plan the disassembly of LCD televisions.

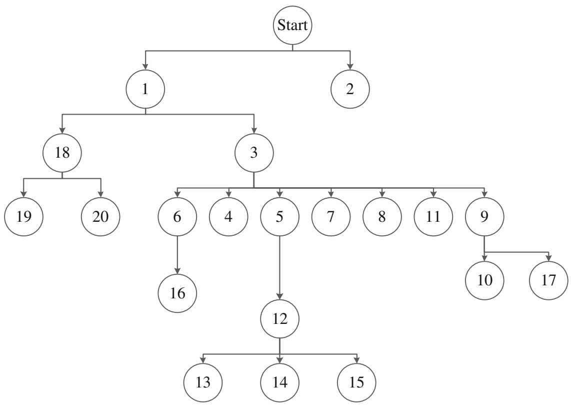
As discussed earlier, in the disassembly planning process of LCD televisions, it needs to address environmental, economic and feasibility issues. Environmental regulators need to ensure that specific targets with regard to the remanufacturing and recycling of LCD televisions are adhered to, and remanufacturers expect to isolate components that can generate higher potential re-use values from the overall assembly in a timely and efficient manner to ensure that labor overheads are maintained as low as possible [24].

The hazardous materials contain substances that are harmful to humans or directly harmful to the environment. Some hazardous materials are parts of LCD televisions, such as PCBs, which often contain Tin, Lead, Cadmium and capacitors containing polychlorinated biphenyls, and the LCD screen, which contains fluorescent tubes with Mercury and liquid crystals.

According to the WEEE Directives, components in WEEE with the hazardous materials need to be disassembled and then recycled (e.g., The EU WEEE Directive states that PCBs greater than 10 cm^2 need to be removed from WEEE). It is also required to disassemble at least 75 % components from a set of WEEE. In a LCD television, key components contribute significantly to the overall weight of the LCD so that they should be handled first to improve disassembly efficiency. Meanwhile, another key issue to achieving successful recycling is to ensure that there is an economic gain from the disassembly process.

Based on the BoMs of the LCD television of the type of LC24F4, the process of disassembly can be planed. Figure 2.6 is used to represent the constraints of the disassembly plan and called the disassembly constraint graph. Except the disassembly constraint graph, there are several other methods to represent the disassembly constraints, such as disassembly tree, state diagram and And/or Graph [21]. In the graph, nodes represent operations and connection lines represent the precedence constraint relationships between operations. Meanwhile, each operation is

Fig. 2.6 The disassembly constraint graph



defined with several properties, such as disassembly operation number, disassembly operation time, component(s) (name, amount, and mass) to be disassembled by each operation, and potential recovered component(s)' mass, potential value and hazardousness. Table 2.1 lists the properties of the disassembly process according to the disassembly operation number.

2.3.2 Selective Optimizations and Comparisons

2.3.2.1 An Initial Plan

According to the constraints, different disassembly plans can be created. One of these chosen is (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20). Its physical disassembly process is shown in Fig. 2.7. This plan is called "*an initial plan*" to be used in the following Scenarios for the comparisons with an optimized plan for a better understanding of the optimization process.

2.3.2.2 Scenario 1 for Selective Optimization

It is aimed to determine a selective optimization disassembly plan (part of the full disassembly plan) to meet the environmental protection targets (100 % hazardousness removal and 75 % component disassembled for the whole WEEE) and achieve the optimized potential recovery value (all the three weights in Forumar (2.5) were set 1). The input data is shown in the Table 2.1.

The disassembly planning selection and optimization process is shown in Fig. 2.8a. During the computation process, results were normalised, i.e., the index result of each operation was converted as the percentage of the overall results of all the operations. The results in the Y axis were also accumulated for the operations.

The hazardousness removal, weight removal and potential recovery value for the initial plan (shown in the previous Fig. 2.7) and an optimized plan are shown in (b), (c) and (d) respectively. In (b), a 100 % hazardousness removal target will be achieved after 13 disassembly operations for the optimized plan, In (c), a target to achieve 75 % component disassembled by weight (of the total weight of the WEEE) took 6 operations for the optimized plan,. In (d), the result of potential recovery value divided by spent time for each operation is shown, which is a target to achieve the most potential recovery value within the shortest time. To meet the environmental protection targets of removing 100 % components with hazardous materials and 75 % components by weight to be disassembled, the first 13 disassembly operations were selected from the optimized plan as the selective optimized plan. Meanwhile, the potential recovery value and spent time for this plan was optimized in this selective plan.

In (b) and (c), it can show that the initial plan will take 15 disassembly operations to achieve 100 % hazardousness removal, and also 15 operations for 75 %

Table 2.1 Disassembly operations and some properties of the LCD television

Disassembly operations	Time (s)	Components	Mass (g)	Potential value (Yuan)	Hazardousness removal
1. Unscrew and remove base part	86.4	Base part	1.8	0.0119	Low
		M4x12	1.6	0.0106	
2. Unscrew and remove cover plate	86.4	4x10BTECh	11.2	0.0739	Low
		Cover plate	23.0	0.1840	
		3x10KTHCh	0.6	0.0004	
3. Remove back cover part	43.2	Support structure	15.6	0.1248	Low
4. Disassembly back cover part	21.6	Back cover	723.8	1.7904	Low
		Insulation board	25.0	0.2280	
5. Remove wire with pin	86.4	Wire with pin	50.0	0.1000	Low
6. Remove power switch part	43.2	Power switch part	5.0	0.0100	Low
7. Remove control button part	43.2	Control button	3.7	0.0050	Low
		Control button part	5.5	0.0050	
8. Unscrew and remove main board	129.6	Main board	196.0	0.7908	Relatively high
		M3x8GB/T9074.4	3.0	0.0021	
		Insulating washer	3.0	0.0100	
9. Unscrew and remove loudspeaker part	86.4	Loudspeaker part	60.0	1.3000	Low
		M3x8GB/T9074.4	2.0	0.0040	
10. Unscrew and remove power supply board and insulating board	86.4	Power supply board	118.0	0.6466	Medium
			25.0	0.1520	
		Insulating board	0.5	0.0033	
		M3x8GB/T9074.4	0.6	0.0004	
		M4x8GB/T9074.4			
11. Unscrew and remove metal support	86.4	Metal support	183.0	1.2078	Low
		M4x8GB/T818	2.4	0.0158	
12. Unscrew	86.4	4x8BTHCh	7.2	0.0475	Low
		Clamping bush	24.0	0.1584	

(continued)

Table 2.1 (continued)

Disassembly operations	Time (s)	Components	Mass (g)	Potential value (Yuan)	Hazardousness removal
13. Remove loudspeaker	43.1	Loudspeaker	77.8	0.0600	Low
14. Remove remote control receiver board	21.6	Remote control receive board	3.0	0.4000	Medium
15. Separate surface frame and LCD screen	21.6	Surface frame	270.8	1.1000	High
		LCD screen	2900.0	9.6684	
		Metal mounting plate	639.0	1.2170	
16. Disassemble power switch part	64.8	Power switch	5.0	0.0100	Low
		Power wire	75.5	0.1000	
		Wire with pin	5.0	0.0100	
17. Disassemble loudspeaker part	64.8	Loudspeaker	152.0	0.6000	Low
		Support	95.0	0.0200	
		Washer	2.0	0.0070	
		4x8BTHCh	2.4	0.0158	
18. Disassemble base part	86.4	Metal washer 1	10.0	0.0660	Low
		Metal washer 2	10.0	0.0660	
		Metal fixing plate	15.0	0.0990	
		M4x12GB/T818	2.4	0.0158	
19. Disassemble brace part	86.4	Metal support	25.0	0.1650	Low
		Plastic support 1	30.0	0.2400	
		Plastic support 2	20.0	0.1600	
		M4x12GB/T818	2.4	0.0158	
20. Disassemble seat part	64.8	Toughened grass seat	150.0	0.3300	Low
			50.0	0.0640	
		Steel plate	20.0	0.0200	
		Rubber gasket			

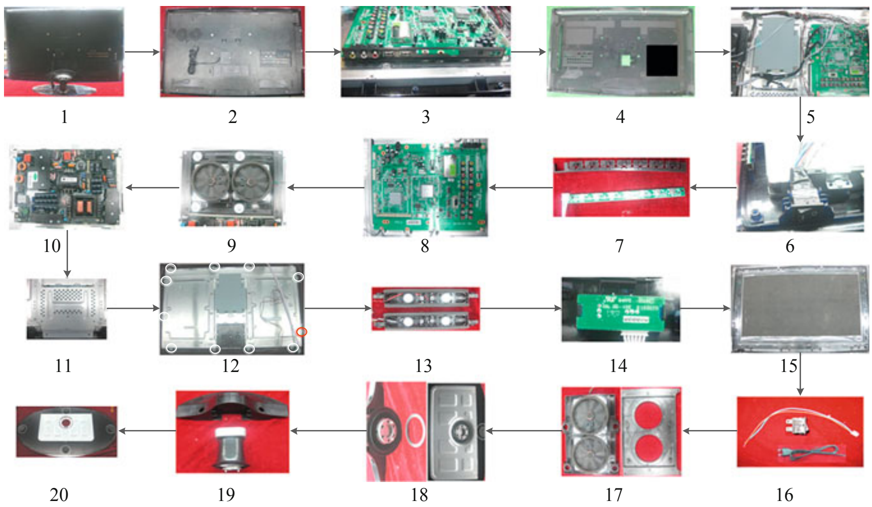


Fig. 2.7 A disassembly plan of the LCD television (an initial plan)

components by weight to be disassembled. Therefore, 15 operations are necessary to achieve the environmental protection targets. Therefore, the optimized plan will have 2 less operations. The potential value/time in (d) can be separated and interpreted in (e) and (f). It shows that with the selective optimized plan, the potential recovery values during the disassembly process are 86.7 % (of the total potential value of all the disassembled components in the WEEE) for 13 operations, and 38.8 and 85.8 % for the initial plan after 13 and 15 operations respectively. With the selective optimized plan, the time spent during the process were 62.7 % (of the total time spent to disassemble the WEEE) for 13 operations, and 69.4 and 77.6 % for the initial plan after 13 and 15 operations respectively.

Therefore, if the first 13 operations are selected for both plans, it can be observed that significant potential value is recovered (86.7 vs 38.3 %) while less time spent with the optimized solution (62.7 vs 69.4 %). If the first 13 operations and 15 operations are selected for both plans respectively, a better potential recovery value (86.7 vs 85.8 %) while about 15 % time of the total disassembly time can be saved with the optimized solution (62.7 vs 77.6 %). 15 % labor time of disassembling a single set of LCD WEEE stands for 200 s, and about 6 h for 100 sets of the LCD WEEE.

2.3.2.3 Scenario 2 for Selective Optimization

It is aimed to prioritize the environmental protection targets (100 % hazardousness removal and 75 % component disassembled for the whole WEEE) (the weights for the Hazardousness Index and Weight Removal Index in Formula (2.5) were set 1

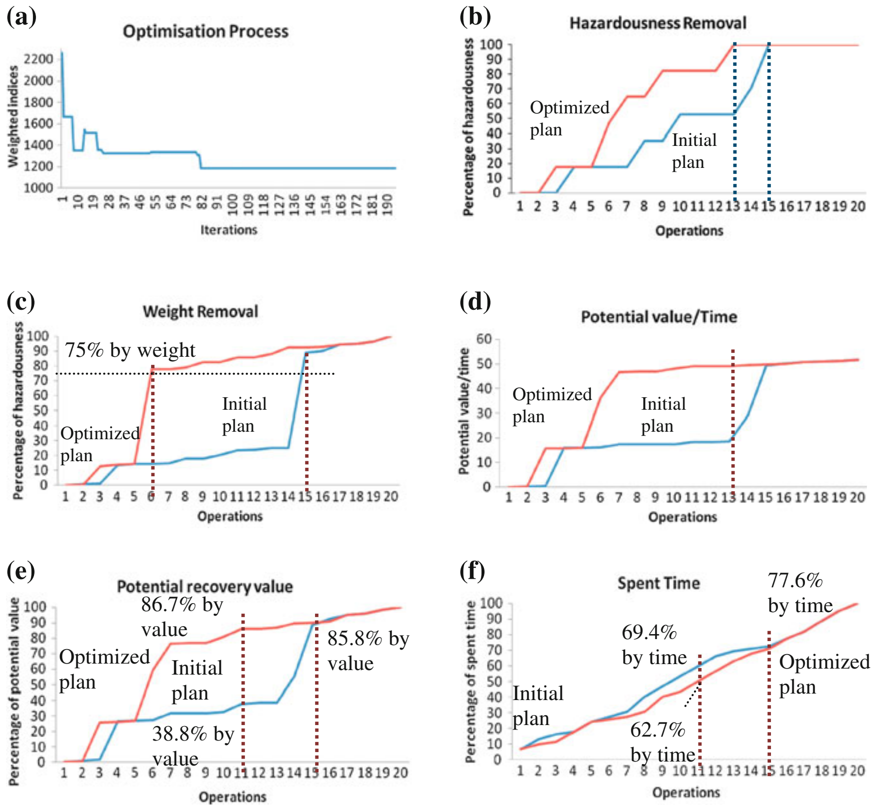


Fig. 2.8 Optimization processes for scenario 1 (all weights are 1) **a** The disassembly planning optimization process. **b** Hazardousness removal during disassembly. **c** Weight removal during disassembly. **d** Potential recovery value/spent time during disassembly. **e** Potential recovery value during disassembly. **f** Spent time during disassembly.

and the weight for Potential Recovery Value 0.5). The input data is shown in the above Table 2.1. The comparison results are shown in Fig. 2.9.

In Fig. 2.9a, a 100 % hazardousness removal target will be achieved after 10 disassembly operations for the optimized plan with this weight setting. In (b), a target to achieve 75 % component disassembled by weight (of the total weight of the WEEE) took 7 operations for the optimized plan with this weight setting. Therefore, 10 disassembly operations are needed for the selective optimized plan, compared to 13 operations in Scenario 1. In (c), the time spent for the 10 operations is 50.0 % of the total time for the WEEE, which can be compared to the related results of Scenario 1, which were 62.7 and 69.4 % of the total time spent to disassemble the WEEE for the optimized plan with all the weights were set 1 and the initial plan for 13 operations, respectively. In (d), the potential recovery value is 77.4 % of the total potential value of the WEEE for this setting, while the potential recovery values are 86.7 and 38.8 % of the total potential value of all the disassembled components in

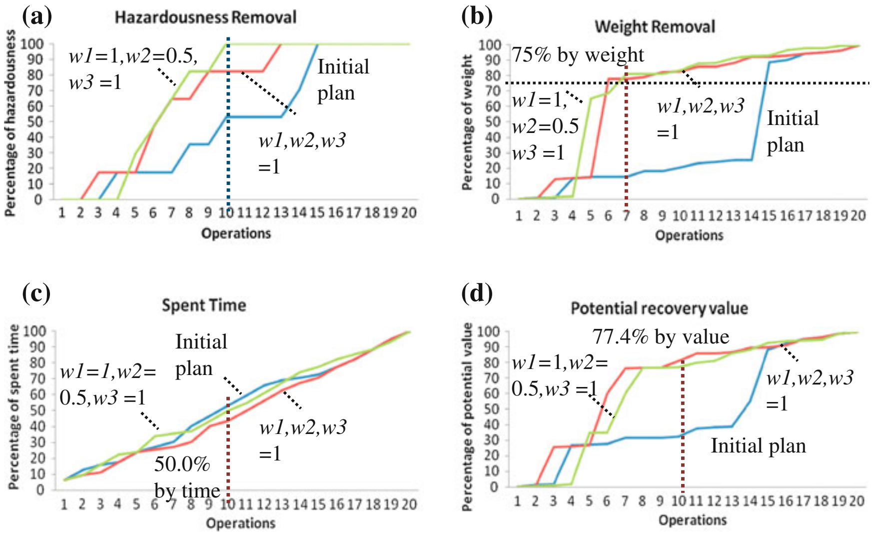


Fig. 2.9 Optimization processes for Scenario 2 (different weights) **a** Hazardousness removal during disassembly. **b** Weight removal during disassembly. **c** Spent time during disassembly **d** Potential recovery value during disassembly

the WEEE for the optimized plan and the initial plan in Scenario 1, respectively. It can be clearly observed that with the prioritized considerations of hazardousness and weight removal, less operations and time are needed accordingly while the potential recovery value has to be traded off (from 86.7 to 77.4 %).

2.3.2.4 Environmental Impact Evaluation

Disassembled components can potentially generate values through component re-use/re-manufacturing and material recycling, and they can therefore reduce the environmental impact and climate change effect without the need to make the components from raw materials. The environmental impact and climate change effect of each operation is shown in Table 2.2. The results of the optimized plan under Scenario 1 (all the weights were set as 1) and the initial plan are shown in Fig. 2.10. It can be observed that significant improvements can be made with the optimization process compared to the initial plan (69.4 and 155.3 % improvement in the two aspects).

2.3.2.5 Algorithm Comparisons

Meanwhile, the developed algorithms developed in this research was benchmarked to demonstrate their innovations. The generic constraint handling method in this research was compared with a classic penalty method [28], which is a popular

Table 2.2 The avoided environmental impact/climate change effect of each disassembly operation

Oper(i)	Avoided environmental impact (10^{-3} Pt)	Avoided climate change effect (10^{-8} DALY)
1	2.54	1.53
2	13.20	3.37
3	20.12	4.44
4	349.02	57.61
5	349.02	57.61
6	349.02	57.61
7	349.02	57.61
8	351.26	58.96
9	352.75	59.87
10	358.59	62.85
11	496.90	146.47
12	520.17	160.54
13	520.17	160.54
14	520.17	160.54
15	1111.69	465.03
16	1111.69	465.03
17	1184.35	508.96
18	1212.25	525.82
19	1254.89	541.60
20	1292.19	564.15

method applicable to complex constraints. The results are shown in Fig. 2.11a. It can be concluded that the developed generic constraint handling method ensures that the computational process can be conducted in a smoother and more efficient way, and all the generated plans are valid.

The GA, SA and improved PSO algorithms were also used for optimization shown in (b). All of them can yield good results but the SA and the improved PSO both outperform the GA in the case studies, while the improved PSO algorithm is better than the SA. Each iteration of the improved PSO algorithm mainly uses simple mathematical operators that can be finished in a shorter time than those for the GA and the SA algorithms with mainly complex position changing operators so that the improved PSO algorithm is also more efficient to achieve the best value generally.

2.3.3 A Disassembly Planning Service in a Distributed Environment

The developed disassembly planning method will be wrapped as a service in a main framework illustrated in Fig. 2.12. In the framework, apart from the disassembly planning method which dismantles a set of WEEE into the component level, the recycling planning method will be used to support the processing of the disassembled components into materials, and the design for Remanufacturability/

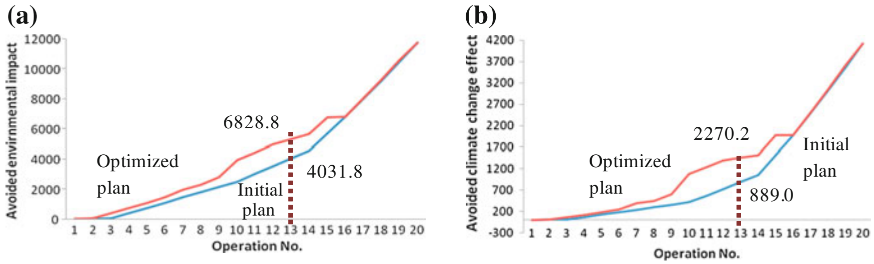


Fig. 2.10 Optimized accumulated avoided environmental impact and climate change effect s **a** Avoided environmental impact. **b** Avoided climate change effect.

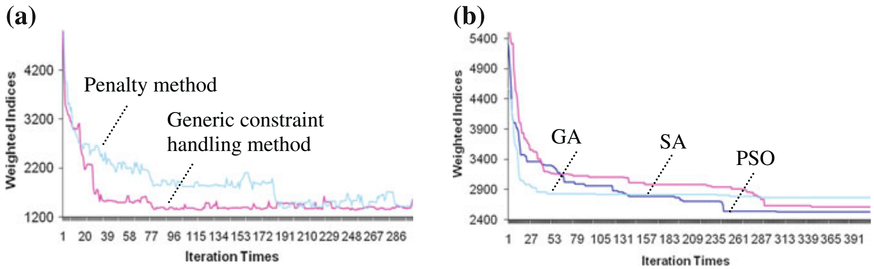


Fig. 2.11 Algorithm comparisons **a** Comparison on constraint handling method. **b** Comparison on intelligent methods

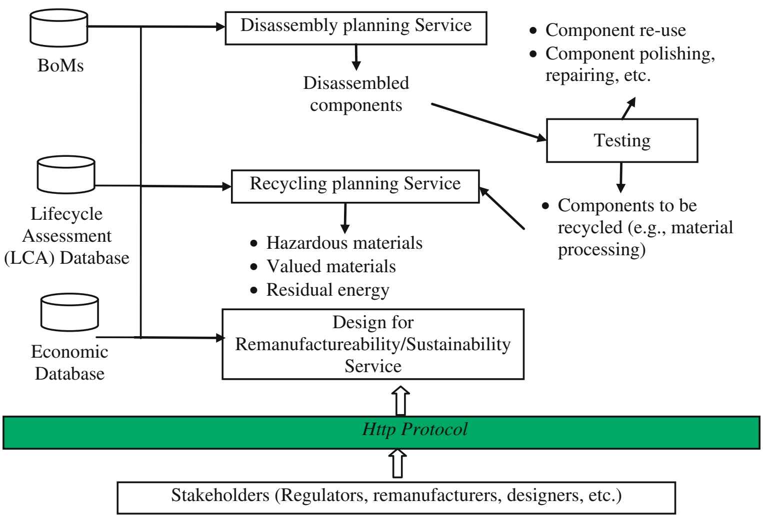


Fig. 2.12 Remanufacturing services and its framework

Sustainability service to support design in a more efficient means. Stakeholders will access the services through the Http protocol remotely.

2.4 Conclusions

WEEE have been increasingly customized and diversified, and the selective disassembly planning of WEEE to support remanufacturing decision-making is an important but challenging research issue. In this chapter, an effective selective disassembly planning method has been developed to address the issue systematically. The characteristics and contributions of the research include:

- An improved PSO algorithm-based selective disassembly planning method with customizable decision-making models and a novel constraint handling algorithm has been developed in a systematic means. In the method, the customizable decision-making models embedded with adaptive multi-criteria to meet different stakeholders' requirements have been designed to enable the method flexible and customizable in processing WEEE effectively;
- Based on the constraint handling and intelligent optimization algorithms, the developed method is capable to process complex constraints for different types of WEEE based on a generic and robust process and achieve selective optimized disassembly plans efficiently;
- Industrial cases on LCD WEEE have been successfully carried out to verify the effectiveness and generalization of the developed research. Different application scenarios and targets have been set to validate and demonstrate that this research is promising for practical problem solving.

In the future, a more intelligent mechanism needs to be developed to generate disassembly constraints from the functions and semantics of the BoMs of EEE automatically and accurately (e.g., not all the assembly constraints will be used to generate disassembly constraints due to the different functions and semantics during EEE assembly and WEEE disassembly). With the mechanism, disassembly plans of WEEE will be generated from the design stage of EEE to support Design for Remanufactureability/Sustainability in a more efficient means.

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Chapter 3
Cloud Machining Community: A Method to Use Socialized Production Resources for Outsourcing Machining Processes and Parts

P. Y. Jiang, W. Cao, F. Q. Zhang, Y. B. Fu and L. Luo

Abstract As outsourcing demands related to machining task are appearing to be increasingly explosive in recent years, especially in small and medium size manufacturing enterprises, a new production and operation phenomenon characterized by outsourcing machining services has emerged consequently. But the distributed machining resources (MRs) in the society limit the execution of these outsourced tasks. Under this circumstance, a Cloud Machining Community (CMC) is proposed in this chapter mainly focusing on outsourced tasks related to machining processes and parts. Furthermore, it could integrate the distributed socialized MRs and provide customers with on-demand machining services to fulfill all the outsourced tasks. The comprehensive framework and operation mode are established firstly, and roles classification in CMC is also talked about. Then, three key enabling technologies are put forward and analyzed in detail, namely virtual access of socialized machining resources, broadcasting and contracting of outsourcing tasks, and machining process monitoring towards a specific outsourcing task. A simple use case fashioning a torque arm of an airplane undercarriage is studied so as to demonstrate the feasibility and applicability of the proposed framework and technologies. Finally, some conclusions are drawn at the end of this article.

3.1 Introduction

Nowadays, the professionally social division of labor in manufacturing industry forces more and more enterprises to focus on their own core business than ever before, and outsource most of the non-core manufacturing activities to other

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professional organizations outside [1]. Machining is one of the most important manufacturing activities. As a result, outsourcing demands related to machining tasks have appeared to be increasingly explosive in recent years, which have also facilitated the emergency of a new production and operation phenomenon characterized by outsourcing machining services [2]. Furthermore, outsourcing machining processes and parts has already become an important business approach, whereby a competitive advantage may be gained when workpieces or services are produced more effectively and efficiently by outside suppliers. It is an agreement in which one manufacturer contracts out a part of their existing internal machining activities to another manufacturer [3].

Outsourcing machining activities in cross-region or even in cross-border environment is extraordinarily expected. But unfortunately, limited by the lack of an effective service platform that integrates socialized machining resources (MRs), in order to share machining information and capabilities and establish a sophisticated trust mechanism [4], the overwhelming majority of manufacturers are suffering from the dilemma that only machining services provided by few dependable partners located in a same region can be obtained without trembling [5, 6]. It means that outsourcing cannot display its functions totally. In other words, plenty of the superfluous machining resources are idle and unknown for other enterprises where need them. From a macro point of view, it in some sense leads to a waste of the manufacturing resources and doesn't meet the requirements of green manufacturing (GM) and low-carbon manufacturing. Therefore, it is obvious how to discover, organize and utilize the distributed socialized machining resources in a much more extensive scope so as to fulfill the abundant outsourcing machining tasks optimally and economically is the most pivotal issue at present and must be figured out immediately.

Focusing on this issue, manufacturing industry has undergone a major transformation to accommodate this new trend for decades. Consequently, many new advanced manufacturing modes (AMMs) have been arisen successively in academic circles since the 1990s, and gradually redefined the way that the entire manufacturing industry is operated [7–9]. The most famous AMMs to deal with the distributed machining resources and outsourcing machining activities mainly include networked manufacturing (NM), manufacturing grid (MG), virtual enterprise (VE), collaborative networked (CN), etc. Although lots of research results have been obtained theoretically and shown the capability to solve part of the issue, many hidden problems have been exposed too which obstruct their practical application and development [10]. For example, the traditional NM primarily reflects the thought of "distributed resources are integrated to be used for one task" [11, 12]. But owing to lacking the centralized operation management of services and the allocation plan of benefit interests, the continuous, stable, and high quality transaction of machining services can't be guaranteed. Some similar imperfections have been reported in other AMMs too. In some sense, the issue mentioned above is still unsolved.

On the other hand, the evolution experience of manufacturing industry reveals a law that the progress of IT (Information Technology) always plays a crucial role in taking full advantage of machining resources and improving the production efficiency in manufacturing industry [13]. Therefore, cloud computing which is to manage distributed computing resources and has been identified as one of the key technology trends can also be introduced into manufacturing to integrate and re-allocate machining resources according to need. In this circumstance, and based on the rapid advance of both hardware and software technologies, a new-type cloud system called cloud machining community (CMC) that shares information and resources among loosely connected manufacturing firms in different regions is proposed in this article. CMC is a kind of new networked manufacturing mode which is mainly used to integrate, organize and allocate the machining resources among regions through internet according to customers' requirements, and provides them with on-demand machining services. It must be pointed out that when comparing with the traditional NM, CMC narrows down its scope and only focuses on the outsourced activities related to machining processes and parts. Furthermore, CMC can realize not only the thought of "*distributed resources are integrated to be used*", but also the reverse thought of "*integrated resources are distributed to be serviced*". It in some sense can be considered as a great development of the traditional networked manufacturing.

The rest of this article is ranged as follows. Section 3.2 clearly describes the operation mode and realization framework of CMC. Several main enabling technologies are discussed in Sect. 3.3, i.e. virtual access of socialized machining resources, broadcasting and contracting of outsourcing tasks, and Machining process monitoring towards a specific outsourcing task. Then, a use case is studied in Sect. 3.4 to demonstrate the feasibility and applicability of the proposed framework and technologies. Finally, some conclusions are drawn in Sect. 3.5.

3.2 Operating Mode and Framework of Cloud Machining

This section will give a comprehensive description about the panorama of the cloud machining community. Specifically, its roles classification, operation mode and the system implementation framework are drawn in detail.

3.2.1 Roles and Jurisdictions in Cloud Machining Community

As the outsourcing tasks in CMC system are limited in a sharp scope, i.e. process machining outsourcing and workpieces machining outsourcing, the main roles involved in the system can be divided into three classes such as platform side, service provider side and service requestor side. In all, there are five kinds of roles in CMC belonging to the three classes like cloud platform providers, platform technical service providers, machining service providers, logistics service providers and service requestors. In addition, different from the operation mode of cloud computing that all services can be provided and employed through internet, actual logistics is essential for the cloud machining community because object flows (e.g. row material flows, WIP flows and finished workpieces flows) are inevitable. Thus, the logistics services provider is considered another important role in CMC. The five kinds of roles involved in CMC are listed and described in Table 3.1.

In addition, different roles have different jurisdictions in CMC. The corresponding jurisdictions of a specific role will be provided on a related cloud-desktop with a series of function and application forms. Here, the cloud-desktop is a customized desktop on which the corresponding applications will be listed when one login the system with a specific role. He/she can use these applications to fulfill some special functions very conveniently. Furthermore, as an individual may have more than one role in CMC, he/she can also re-login the system with another role. Figure 3.1 clearly shows the five kinds of roles in the cloud system together with their jurisdictions.

Table 3.1 Roles involved in CMC

Participants	Roles	Definitions/descriptions
Platform side	Cloud platform provider	A cloud platform provider is a company or an organization that provides the cloud machining platform for both machining services providers and services requestors. It takes charge of the overall plan of the platform, and outsources or crowd sources their IT issues to other technical service providers. In short, it is just responsible for the running issues of the platform.
	Platform technical provider	Some IT companies or individuals are employed to provide services for establishing and maintaining the cloud platform through outsourcing or crowdsourcing.
Service provider side	Machining service provider	In order to make full use of the superfluous machining equipments and capabilities, manufacturing enterprises (or service-oriented machining workshops) that are considered as machining services providers in CMC can add their equipments into the system to provide services to who need them.
	Logistics services provider	Because object flows are inevitable in CMC, some specific logistics enterprises joint in the community to take charge of all the logistics issues involved.
Service users side	Service requestor	Limited by lack of equipments, technology, etc., some manufacturing enterprises choose to outsource part of their non-core machining tasks to cut down cost. They broadcast their tasks and demands through the cloud machining system and search for specific services.

3.2.2 Operating Mode

As mentioned above, the main thrusts of CMC are to configure and re-allocate socialized machining resources optimally, enhance their utilization ratio and reduce resource cost of the society as a whole under the major trend of low-carbon economy. CMC provides a good chance for solving complicated machining problems, sharing machining-and-service resources, and promoting large-scale collaborative manufacturing. It is a new advanced manufacturing mode, and its operating mode is shown in Fig. 3.2. In CMC, the distributed socialized machining resources which are owned by kinds of service-oriented machining workshops are virtually described, registered and broadcasted through a series of standard specification. Further, these resources can be retrieved and matched for on-demand applying. This operating mode can finally realize the idea that “distributed resources are integrated to be used” and “integrated resources are distributed to be serviced”.

In order to illustrate the operating model of CMC clearly and accurately, some important concepts implied in Fig. 3.2 are listed below:

- *Machining resource* (*MR*). Machining resource is a set of all kinds of physical elements involved in the machining activities [14]. According to their usage and characteristics, machining resources can be classified into three types, i.e. machining hardware resources, machining software resources and IT computing resources (as shown in Fig. 3.3). Here, machining hardware resources mainly refer to machining equipments including CNC (Computerized Numerical Control) machining tools, machining center, cutting tools, etc. Machining software resources cover the professional software used in machining activities, such as ProE, AutoCAD, Mastercam, and other system management and control

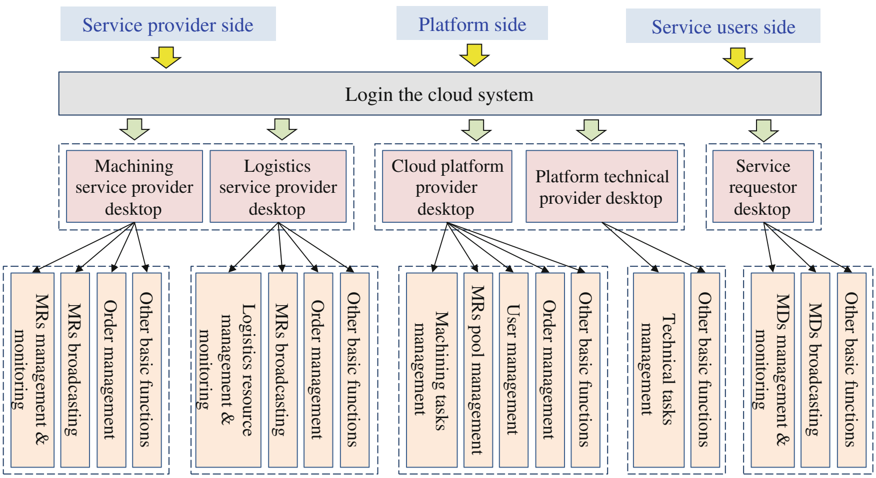

Fig. 3.1 The jurisdictions of the five roles in CMC

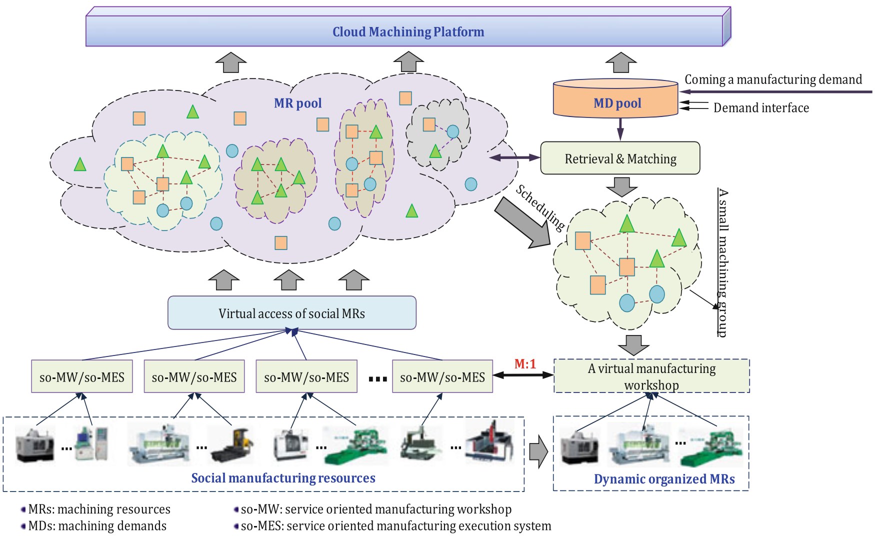

Fig. 3.2 The operating mode of the CMC

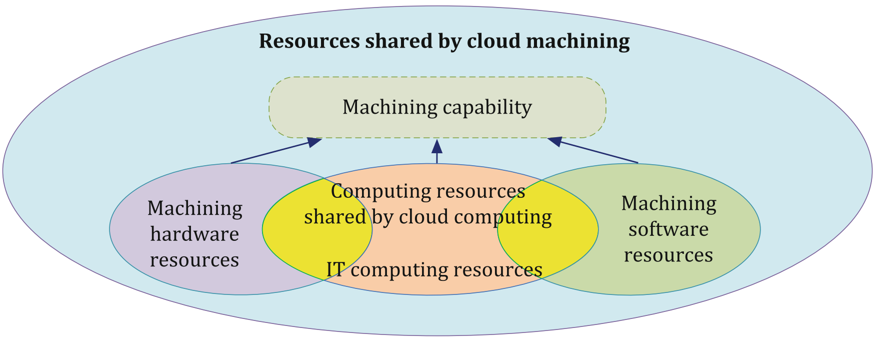

Fig. 3.3 Resources in cloud machining community

software such as so-MES (service-oriented Manufacturing Execution System), SPC (Statistical Process Control), etc. IT computing resources are the hardware infrastructures involved in the informationization manufacturing processes including memory devices, CPU (Central Processing Unit), I/O terminals and available networks. These three kinds of machining resources work together to produce the so-called "machining capability" which can be used to provided machining services for outsourced tasks.

- *Service-oriented machining workshop* (*so-MW*). Service-oriented machining workshop is a generalized definition of the manufacturing communities (i.e. workshops, enterprises, etc.) that mainly focus on providing value-added services about machining processes and parts for customers who need them.

Undertaking and fulfilling outsourced tasks is their profitable way. It is worthwhile to note that the distributed socialized machining resources are fragmented and owned by kinds of these so-MWs. What's more, sometimes a so-MW itself can also be considered as a kind of machining resource too.
- *Machining resource pool* (*MR pool*). When machining resources (usually so-MWs) are virtualized and registered in CMC through a series of SOA (Service-oriented Architecture) standard specification provided by the system, they are stored together and subsequently form a virtually machining resource pool in the system database.
- *Machining group* (*MG*). As shown in Fig. 3.2, part of the machining nodes (so-MWs) usually gather together forming a MG. so-MWs in this community are deeply trusted and collaborate with each other, and they also have higher creditworthiness level in CMC according to its trust mechanism. Not only a number of so-MWs with the same specialty can comprise a MG (e.g. dozens of so-MWs that only deal with deep hole machining gather together comprising a group like a deep holes machining association), but so-MWs along a supply chain can also make up a group. The gathering rule is freewill. Actually, so-MWs in the cloud system comprise plenty of this MGs spontaneously which make up the main body of the resource pool. As a workshop may has several specialties (e.g. it can machining both deep holes and oversized-ultraprecise flat-surface), it can participate in several MGs at the same time. What's more, there also are some workshops that don't belong to any of these MGs. These workshops with lower creditworthiness level can join a relevant MG through enhancing their creditworthiness indexes.
- *Machining Demand pool* (*MD pool*). Similar with the MR pool, when machining demands and tasks coming from service requestors gather together, the machining demands pool is formed. For each of the tasks stored in the demands pool, the cloud system will retrieve the machining resources pool and choose a group of resources optimally that matching the task's requirements. Thus, a dynamic resources group is generated like a virtual machining workshop whose machining equipments actually belong to a number of physical distributed workshops. The ratio between a virtual workshop and the physical workshops is $1 : M$ and where M is variable. This virtual machining workshop maybe comprises of a machining community or several of this communities together, or workshops belonging to several communities, etc. There is a temporary management committee for every virtual workshop to make sure the assigned task is well-done (or a settled committee for a MG). The task allocation mechanism is also deeply related to the creditworthiness level.

3.2.3 System Implementation Framework

Cloud machining community is a new-type and pint-sized networked manufacturing service platform which mainly faces the vast small and medium-sized enterprises in the society, and integrates the latest technologies such as cloud computing, cloud security, the internet of things, etc., to promote the deeply sharing and cooperation of machining resources among these enterprises based on internet. In order to find out the hierarchical structure of the system and the logic relationships among its layers for drawing the blueprint of the system, this article proposes a cloud machining community framework as shown in Fig. 3.4.

According to Fig. 3.4, there are five layers in the core of the cloud system, that is, infrastructure layer, technical support layer, business and service layer, application layer and user layer. In between, infrastructure layer is the bottom layer which provides the basic hardware environment of the system such as cloud servers, cloud databases, cloud memory, internet/intranet, and so on. Comparing to cloud computing, this layer can somehow be considered as Iaas (Infrastructure as a service). Technical support layer deals with the core enabling technologies for the system, e.g. virtual access of socialized MRs, broadcasting and contracting of outsourcing tasks, and machining process monitoring towards a specific outsourcing task. Detailed information about these three technologies will be described in the next section. Business and service layer and application layer are two adjacent layers that closely cooperate with each other. In other words, business and service layer provide service for networked services for the applications in the application layer, such as MRs sharing service, machining business model, cooperation business model, and matching and trade service, etc. On the other hand, application layer can provide on-demand machining services for users based on the support of business and service layer through a series of independent

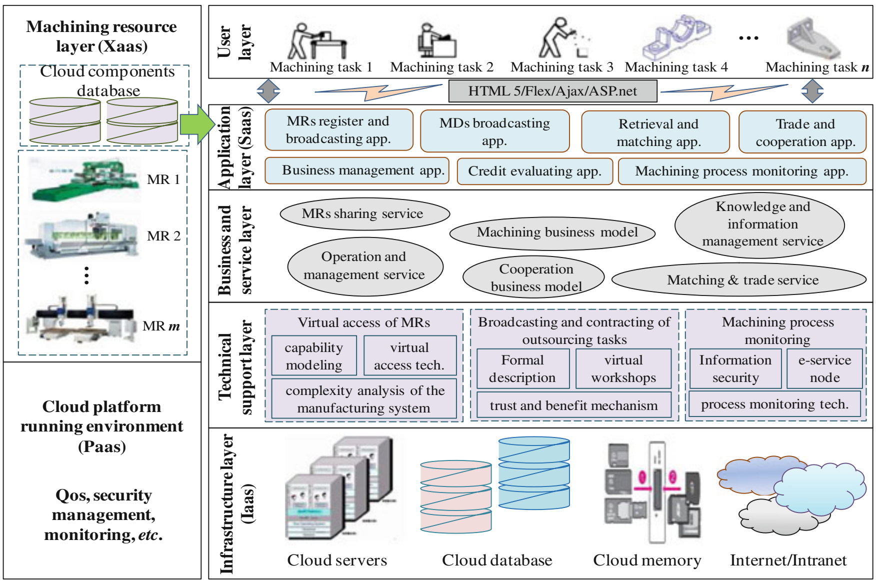

Fig. 3.4 The framework of CMC

applications. Clearly, these applications cover MRs register and broadcasting, MDs broadcasting, retrieval and matching, trade and cooperation, etc. Meanwhile, application layer is also considered as Saas (Software as a service) when comparing to cloud computing. User layer is the topside layer of the cloud system where users represent the requestors. As a consequence, this layer mainly deals with the access and management of all kinds of machining tasks.

Besides, two other circumjacent layers are also included in the cloud system, that is, cloud platform running environment and machining resource layer. In between, cloud platform running environment considered as PaaS (Platform as a Service) provides the basic running environment such as QoS (Quality of Service), security, management and monitoring, etc. Similar with user layers, the machining resource layer focuses on the resource providers and deals with the access and management of all kinds of machining resources, both physical and virtual.

3.3 Key Enabling Technologies

According to the distributed, isomerous and service-oriented characteristics of the machining resources in the CMC environment, in this section, several key enabling technologies are represented in detail, that is, virtual access of socialized machining resources, broadcasting and contracting of outsourcing tasks, and machining process monitoring towards a specific outsourcing task.

3.3.1 Virtual Access of Socialized MRs

3.3.1.1 Dynamic Production Capability Modeling of Service-Oriented Machining Devices/Workshops

In order to integrate the MRs distributed all over the society, virtualization technology is one of the most effective technologies and hence introduced in this chapter to realize the virtual access of socialized MRs. For the first step of virtualization technology, the dynamic production capability modeling of service-oriented machining devices/workshops is of great importance. It is considered as a core of the machining community system because a well-built capability model can provide accurate information to support the subsequent retrieval and matching. As CMC mainly deals with the outsourced machining tasks, machining resources involved in this article are limited to machining devices, such as turning machines, milling machines, CNC centers, etc. According to the demands of both of CMC and service requestors, two capabilities including machining capability and production capability are extracted from the viewpoint of machining targets, delivery date, quality and cost.

For a single machining device, as shown in Fig. 3.5, machining function and machining performance are defined to evaluate its machining capability. In order to describe the model clearly, some importance concepts involved should be clarified at first.

- *Machining function* means a set of features that a MR can finish. e.g. a vertical milling machine has the function of mining a surface.
- *Performance* is the evaluation of a single machining function. It contains the highest accuracy, surface quality, etc., that the machining function can reach.
- *Performance quality* is used to evaluate the stability of a MR when fulfilling a machining function. It reflects the tolerance distribution of machining a batch of workpieces.
- *Machining capabilit*y figures out which machining functions a MR have, what performance it can reach, and how about the stability of the MR when it machining a batch of workpieces.
- *Production capability* is a conventional concept that mainly deals with the amount of workpieces that a MR can fulfill in a unit time interval. It somehow relates to the delivery date of an outsourced task.

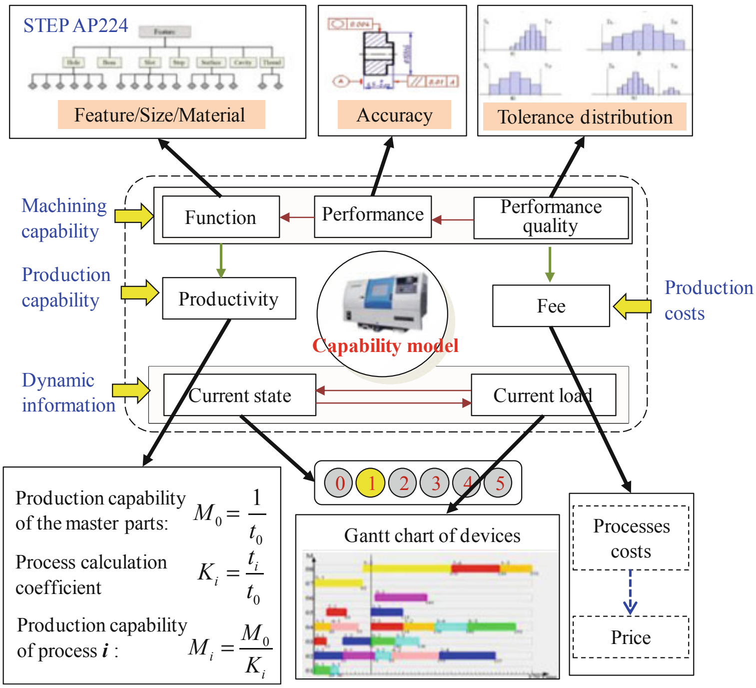

Fig. 3.5 Capability model of a single machining device

The above concepts focus on the capability model of a single MR. As for a machining workshop, however, it is a combination of a set of MRs. Thus similarly, the capability model of a machining workshop can be established easily.

Generally, machining function is implied by the features that a MR can machine. The classification of all the features can refer to STEP AP224 Standard [15]. Performance can be considered as a constriction of the machining function, that is, the highest accuracy and surface quality. Actually, accuracy and surface quality are very relative to a feature. Therefore, different machining functions usually have different performances. As the states of MRs in the cloud machining environment are changing by time, a dynamic information model is also necessary for scheduling and monitoring the MRs timely. Here, the dynamic information mainly includes the running state of each MR together with its current working-load, which is demonstrated by a kind of Gantt chart. What's more, price and cost are also very important information for describing a MR.

3.3.1.2 Virtual Access and Formalized Description of MRs

The virtualization of MRs means encapsulating the MRs and putting the virtual MRs into the resource pool of CMC. A standard and open encapsulating method that provides unified interfaces to connect distributed MRs and CMC is the base of sharing and configuring optimally socialized MRs. Here, this chapter realizes the encapsulation of MRs by employing Web Services Description Language (WSDL). Simple Object Access Protocol (SOAP) is also applied to shield the diversity among different soft platforms. Different kinds of web services are related to different kinds of physical MRs, and usually one MR connects only one web service. CMC visits these web services through their access points, and calls their remote methods to control and command the corresponding physical MRs. Because of the diversity of the communication methods and the needed information among different MRs, the encapsulation procedures of different MRs need to define different methods and operations according to the intrinsic functions of the MRs themselves. Figure 3.6 reveals the realization procedure of a web service. Firstly, use WSDL to define the visiting operations and port address of each web service according to a related physical MR; then, develop a web service interface for each MR according to the WSDL document; finally, develop Java classes to realize these interfaces.

Although physical MRs are connected to CMC by the above virtualization procedure, we still need to establish a descriptive model for transforming these physical MRs into virtual ones and subsequently store them in the MR pool. Therefore, this article proposes a virtual MR descriptive model from the viewpoints of resource identification, basic information, capability information and mapping relationships, etc., as shown in Fig. 3.7.

After the descriptive model has been established, a formalized description of the MRs can be realized by using Set Theory and Relational Algebra. Here, a five-element-array is built for this purpose as follows:

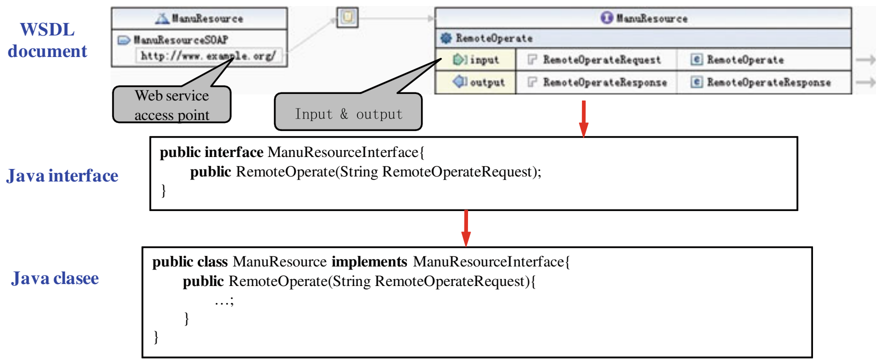

Fig. 3.6 Virtual access of MRs based on web service

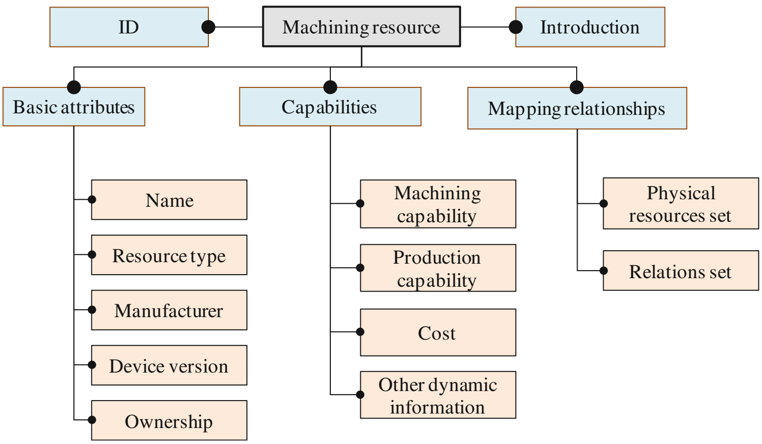

Fig. 3.7 Descriptive model of MRs

$$VirtualResource = \{VRID, VRIntro, VRBasicInfo, VRCapaInfo, VRMapInfo\}$$

where *VRID* is the unique ID of a virtual MR in the CMC system. *VRIntro* represents the introduction of the MR, which shows its brief and original information for both service requestors and platform providers. *VRBasicInfo* is the basic attribute of the MR including resource name, type, manufacturer, version, ownership, etc., to provide basic information for the management, scheduling, statistics and analysis of MRs. *VRCapaInfo* describes the capabilities of the MR such as machining capability, production capability, cost and other dynamic information related to its capabilities. *VRMapInfo* stands for the mapping relationship between the physical MR and the corresponding virtual MR.

When the virtual MRs are described formally, the MR pool can be modeled easily. Actually, the MR pool is a supergiant set that comprises of all the virtual MRs and their information.

3.3.1.3 Complexity Analysis of the Socialized Manufacturing System

The above sections aim to describe the service-oriented machining devices/ workshops and to reveal their information interaction mechanism for joining the CMC. Here, the distributed MRs including devices and workshops provide a basis for establishing the cloud machining community, and they are virtualized and accessed to MR pool in term of different classification ways. There are four classification ways considered. (1) The small machine tools with simple functions could be abstracted as single virtual resource, such as lathe CA6140; (2) The compound machine tools with multiple functions could be abstracted as several virtual resources, such as machining centre GMX200Slinear, DMG; (3) Several machine tools with different functions could abstracted as one virtual resource. For example, drilling, milling and boring machines are combined to fulfil the machining of Boeing 787s landing gear; (4) Several machine tools with different functions could be abstracted as more than one virtual resource. For example, the function modules of compound machine tool (GMX200Slinear, DMG) could de decomposed and restructured into milling and drilling resources. Based on the above classification ways, the different MRs could be reorganized and the MR pool could be established, as shown in Fig. 3.8.

The goal of establishing MR pool in CMC is to realize the proper utilization of the whole socialized resources, reduce resource wastes and enhance the manufacturing capacity. However, different physical location, spare time, service capacities and patterns of these virtual machining resources would lead to the complex characteristics of CMC.

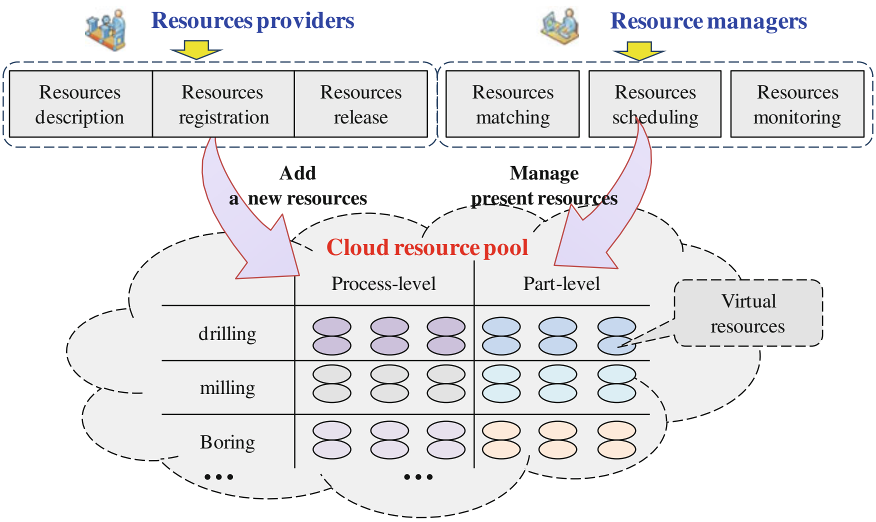

Fig. 3.8 The MR pool in CMC

- *Encapsulation of MRs.* Due to the surplus machining capacity of resources, their providers would like to accept other machining tasks so as to maximize *their utilization and obtain more benefit.* In CMC, machining resources are abstracted as e-service nodes with input and output interfaces, through which the various information could be exchanged and pushed. CMC is responsible for the planning, scheduling and monitoring of all the virtual resources. There is a long-term or short-term collaboration relationship between a resource provider and CMC.
- *Dynamic MR pool.* Due to that the space time, machining and production capabilities of resources may be different, the established MR pool is dynamic and changeable. What's more, some new MRs may be added and the previous machining resources may be dropped out too. Furthermore, the resources are distributed around different areas. All these factors would lead to the difficult planning and scheduling of total manufacturing system.
- *Energy conservation and emissions reduction.* The socialized manufacturing system has wide economic, social and ecological benefits. For example, it would raise the resources utilization and reduce the idle and waste of advanced machine tools distributed around different areas. Actually, the advanced machine tools would have a wide utilization since they have more machining functions, higher machining performances and lower energy consumption in CMC.

3.3.2 Broadcasting and Contracting of Outsourcing Tasks

According to the operating mode of the CMC that is driven by the outsourced machining tasks/demands, and similar with machining resources, a reasonable and convenient broadcasting mechanism of these tasks is necessary and of great importance too. Therefore, this section focuses on the broadcasting and contracting of outsourcing tasks through analyzing their characteristics, establishing a formalized descriptive model, and generating a virtual service-oriented machining workshop for each task. In addition, models of pricing, trust and benefit distribution are also described in detail.

3.3.2.1 Formalized Description of Outsourced Process Machining Tasks

In CMC environment, service requestors outsource their machining tasks to those service-oriented machining workshops that have surplus machining resources and capabilities through CMC. Due to lack of the ability to fulfill all the machining processes independently, lots of small and medium enterprises choose to outsource part of their machining activities to their partners. As a result, abundant outsourced machining tasks are generated. It worth noting that the outsourced machining tasks only represent the outsourcing activities related to machining processes and parts. By analyzing the traditional outsourced machining tasks and combining the configuration of MRs in the CMC, this article establishes a formalized description model for the outsourced machining tasks, which include their basic attributes, machining objects, production requirements, technical requirements and cost, etc., as shown in Fig. 3.9.

After the description model has already been established, a formalized description of the outsourced machining tasks can be realized too. Similarly, a four-element-array is built for this purpose as follows:

$$ProcessTask = \{PrBasicInfo, PrMachObject, PrProductRequir, PrExtraRequir\}$$

where *PrBasicInfo* stands for the basic information of the outsourced machining task, such as task ID, name, concise description and promulgators, etc.; *PrMachObject* contains the machining object information of the outsourced machining task, including features, accuracy, tolerance distribution, etc., as shown in Fig. 3.9. *PrProductRequir* represents the production requirements of the outsourced machining task. Some detailed information such as delivery data, batch and division, etc., is involved in it. *PrExtraRequir* means the extra requirements of the outsourced task including technical requirements, delivery requirements and cost requirements, etc.

As the outsourced machining tasks are broadcasted through internet in CMC, the above mathematic description model of these tasks cannot satisfy the demand. Another description method based on the mathematic model by using IT technology is needed. Therefore, Extensible Markup Language (XML) as a standard structured source language in cross-platform condition is widely used for storing data and transforming information on internet. Here, XML is also applied to establish a digitized description method of the outsourced tasks that can be identified by computers (as shown in Table 3.2).

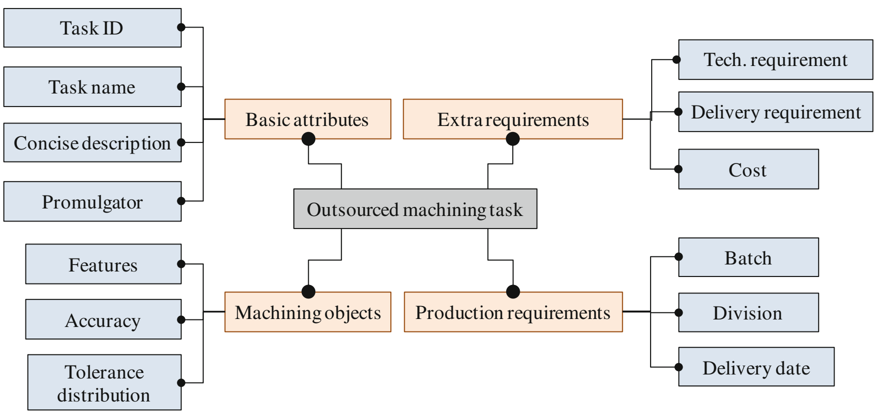

Fig. 3.9 Description model for an outsourced process machining task

Table 3.2 Digitized description method of a process machining task based on XML

Line number	XML code
1	<?xml version = ”1.0” encoding = ”gb2312”?>
2	<ProcessTask>
3	<PrBasicInfo>
4	<TaskID>PrT201204170001</TaskID>
5	<TaskID>precision boring of deep holes on outer cylinder of an undercarriage</TaskID>
6	<TaskIntro>precision boring of deep holes,with accuracy level XX,surface roughness XX</TaskIntro>
7	<Customer>XX undercarriage company</Customer>
8	</PrBasicInfo>
9	<PrMachObject>
10	(hole,cylindricity,mean value,upper limit,lower limit,qualified rate)…
11	(hole,verticality,mean value,upper limit,lower limit,qualified rate)
12	</PrMachObject>
13	<PrProductRequir>
14	<LotSizing> 120 </LotSizing>
15	<Batch> 10 </Batch>
16	<DueDate> 10 months </DueDate>
17	</PrProductRequir>
18	<PrExtraRequir>
19	<TechRequirement>require to use Italian deep hole processing machine tools to fulfill the machining task</TechRequirement>
20	<DeliveryRequirement>delivery a batch of finished products to XX place at the end of each month</DeliveryRequirement>
21	<Payment>
22	<UnitPrice> XX </UnitPrice>
23	<TotalPrice> XXX </TotalPrice>
24	</Payment>
25	</PrExtraRequir>
26	</ProcessTask>

3.3.2.2 Formalized Description of Outsourced Part Machining Tasks

The above description model mainly focuses on process machining tasks. But more usually, a coming machining demand is a part machining task. Thus, a description model for the outsourced part machining tasks is necessary. AND/OR tree is applied in this article for decomposing a typical part machining task into several smaller process tasks hierarchically. In between, each node of the tree represents a machining task and the directed edge between two nodes stands for the inclusion relation of father node and child node. Some related concepts/ assumptions are defined as follows:

- The root node of the AND/OR tree is the corresponding part machining task which is denoted with *Part_Task*; the middle-class nodes are feature machining tasks which are denoted with *Feature_Task*; and the leaf nodes of the tree are the final process machining tasks which are denoted with *Process_Task*.

- The decomposing and inheriting relationships between two nodes are denoted with predicates *Super_Task_of* and *Sub_Task_of* respectively. Suppose that a father node can be decomposed into several child nodes, yet a child node can only inherit from its father node.

In the part machining task tree, there are two kinds of logic relations among the two neighboring child nodes, that is “AND” and “OR”. According to these two logic relationships, this article defines the flowing three structures among the child nodes as shown in Fig. 3.10.

- “*AND structure*”: the logic relation among the child nodes in this structure is “AND”. It means that only if all the child node tasks have been fulfilled, the father node task is completed.
- “*OR structure*”: the logic relation among the child node in this structure is “OR”, and if anyone of the child nodes has been fulfilled, the father node task is completed.
- “*Mixture structure*”: In this structure, “AND” and “OR” relations exist simultaneously.

Therefore, the decomposing procedure of the part machining task AND/OR tree can be shown as Fig. 3.11.

After establishing the AND/OR tree model of a part machining task to describe its decomposing procedure and the fulfill sequence of the leaf nodes, a similar three-element-array is built as follows:

$$Task\_Tree = \{T, L, R\}$$

where $T = \{task_1, task_2, \ldots, task_n\}$ is the set of all kinds of machining task; $L = \{link_1, link_2, \ldots, link_m\}$ is the set of all the directed edges among the nodes; $R = \{relation_1, relation_2, \ldots, relation_m\}$ is the set of the logic relationships related to set L.

In addition, an outsourced machining task process chain is introduced to describe the fulfill sequence of the decomposed process machining tasks. Therefore, a part machining task can be modeled as follows:

$$PartTask = \{PartBasicInfo, Process\_Chain\}$$

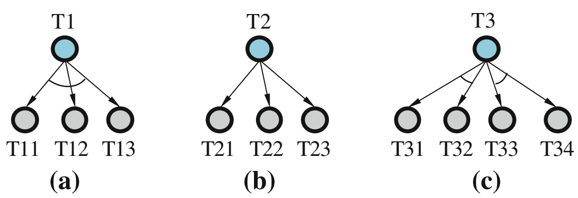

Fig. 3.10 The logic relation among the child nodes

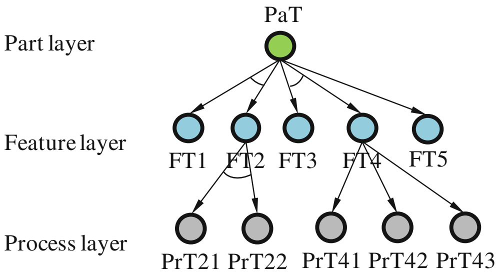

Fig. 3.11 The AND/OR tree model of a part machining task

where providers and community$PartBasicInfo = \{TaskID, TaskName, TaskIntro, TaskPromulgator\}$ includes all the basic information of a part machining task. The child items in *PartBasicInfo* respectively stand for the task ID, task name, task introduction and its promulgator. *Process_Chain* is the process chain of the part machining task.

Similar with the broadcasting of the process machining tasks, the part machining tasks can also be broadcasted through XML technology after the above description model is built.

3.3.2.3 Models of Pricing, Trust and Benefit Distribution

There are various resources providers in CMC, which have short-term or long-term collaboration relationships with the community. Trust mechanism plays an important role in the collaboration among different enterprises. Considering this point, there are many professional groups established in the community. To be specific, the resources providers with good reputation and similar machining capability are clustered into a MG so as to complete the machining tasks of similar parts or processes. For example, through analyzing the historical data collected from machining tasks of large gear, the excellent resources providers are selected to establish a MG. When a new machining tasks of gear released, the resources providers in this MG could be selected first. Therefore, the resources providers within the MG have higher trust and the resources providers out of the group have lower trust. The acquaintance model can be used to describe the trust of resources providers, which is formulated as $\mathrm{AM} = (\mathrm{A}, \mathrm{B}, \mathrm{C})$, where A denotes the resources providers set in the group; B denotes the trust relationship set; C denotes operational symbol of trust relationship. The trust degree between resources provider and CMC could be calculated using the above model too.

In addition, a reasonable solution of benefit distribution between resources providers and community is very important. Aiming to deal with this problem, a Nash-bargaining model considering the estimated cost, expected price and trust degree of resources providers is built, which is formulated as $G = (N, S, Z)$. As illustrated in Fig. 3.12, the players set is formulated as $N = (n_i | 1 \leq i \leq n)$, where n_i denotes the resource providers for bidding the machining tasks; the strategy set is formulated as $S = (S_i | 1 \leq i \leq n)$, where S_i denotes the established cost and

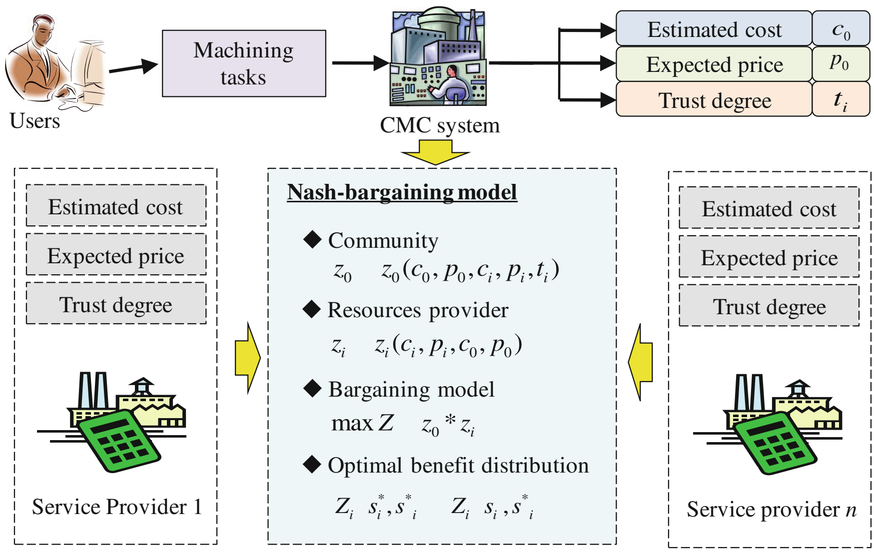

Fig. 3.12 A Nash-bargaining model for resources providers and CMC

expected price of resource providers n_i; the benefit set is formulated as $Z = (Z_i|1 \leq i \leq n)$, where Z_i denotes the benefit of resource providers n_i. According to the above model, its equilibrium point denotes the optimal benefit distribution among resource providers and community, which is formulated as:

$$Z_i\left(s_i^*,\ s_{-i}^*\right) \geq Z_i\left(s_i,\ s_{-i}^*\right)$$

$$where\ \forall s_i \in S_i, s_{-i}^* = \left(s_1^*,\ \ldots,\ s_{i-1}^*,\ s_{i+1}^*,\ \ldots,\ s_n^*,\right),\ i = 1,\ 2,\ \ldots n.$$

It is noted that the research on models of pricing, trust and benefit distribution provides a basis for the generation of virtual service-oriented machining workshops.

3.3.2.4 Generation of Virtual Service-Oriented Machining Workshops

According to formalized description of machining tasks and benefit analysis of resource providers, it is essential for CMC to search and match appropriate resources to establish a virtual machining workshop, in which the machining tasks could be fulfilled. In particular, there are three phases considered to establish the virtual workshops driven by machining tasks, namely searching and matching resources, evaluation of production capacities and cost, configuration of virtual machining workshops.

Searching and matching resources. Figure 3.13 illustrates a specific procedure for searching and matching the candidate resources. First, the matching technique based on fuzzy reasoning is adopted to select resources, whose machining capacities meet the demands of tasks. Then, the matching technique based on

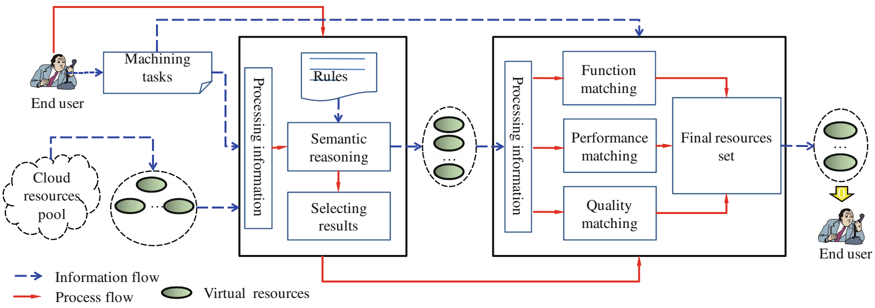

Fig. 3.13 The algorithm of searching and matching candidate resources driven by machining tasks

semantic similarity is adopted to calculate the similarity degree between individual candidate resources and machining tasks, whose purpose is to improve the matching efficiency and accuracy. After these two matching techniques, an optimal candidate resources set is determined.

Evaluation of production capacities and cost. Based on the above candidate resources, whether their production capacities and cost meet the demands of tasks needs to be further assessed. Based on the above description of dynamic production capability modeling of machining devices/workshops and the machining tasks from users, there are two kinds of methods used to evaluate the production capacities and cost of candidate resources. (1) Divide the production capabilities of candidate resources into process-level production capabilities and calculate the time and cost of fulfilling the machining tasks. This method is mainly used to evaluate the process-level machining tasks. (2) Assign the production batches of machining tasks to different resources and calculate the time and cost. This method is mainly used to evaluate the part-level machining tasks. After this evaluation phase, the final resources set of meeting the demands of machining tasks could be obtained.

Configuration of virtual machining workshops. According to the final resources set, the graph theory $G = (V, E, W)$ could be used to formulate the virtual machining workshop. The nodes $V = (v_1, v_2, \ldots, v_n)$ denote different machining resources; the edges $E = (e_1, e_2, \ldots, e_m)$ denote the sequence relation among resource nodes for completing certain machining tasks; the weight $W = (w_1, w_2, \ldots, w_n)$ denote the logistics costs and time between resource nodes.

3.3.3 Machining Procedure Monitoring Towards a Specific Outsourced Task

Machining procedure monitoring towards a specific outsourced task for a dynamic virtual workshop is also a key supporting technology in CMC system to keep it running smoothly. It comprises of several aspects. Firstly, as the monitoring procedure involves the transferring and sharing of information among enterprises, therefore, an e-service node model facing to the outsourced machining tasks is needed for dealing with the related issues such as information security. Then, an e-service node network should be established. Finally, the monitoring model based on the e-service node network will be subsequently built in the dynamic virtual workshop environment.

3.3.3.1 E-Service Node Model of Service-Oriented Devices

Establishing e-service nodes and networks is the most effective tool to realize the monitoring of machining procedures in the CMC environment. Usually, an e-service node is established surrounding a machining device. It is defined as integration and encapsulation of the machining devices and kinds of sensors deployed to it, such as RFID (radio frequency identification), location sensors, temperature sensors, etc. These sensors are used to monitor the current state of the device and machining process, and collect the real-time on-site data for further usage. As a basic monitoring unit to monitor the current machining procedure on a single device, a number of these e-service nodes can make up an e-service node network to monitoring an entire virtual service-oriented workshop.

Actually, an e-service node can be considered as an "information agent", which can provide kinds of information services for upper systems through collecting real-time on-site data around a single device. The framework and workflow of the e-service node model are shown in Fig. 3.14. The information related to a machining device, such as device information, cutting tool information, fixture information, quality information, etc., are collected through the sensors deployed to the device. This information can be further processed into the needed information by Auto-ID computing technology so as to provide real-time information services for the adaptive decision making in the upper systems. It can also reflect the current machining information of the machining devices.

The template of the e-service node mode is the linkage of the upper CMC system and the lower e-service nodes. On one hand, it can provide standard information collected by the e-service node to CMC, obtain the allocated machining tasks and transmit them to the e-service node; on the other hand, it can shield the confidential information of the machining devices or workshops related to their core competence, such as process route, machining parameters, etc. Therefore, the assigned machining tasks can be fulfilled effectively and the information security related to the competence of the registered workshops can be guaranteed simultaneously.

3.3.3.2 E-Service Node Network

As mentioned above, an e-service node is the basic machining and monitoring unit in the virtual machining workshop. In the CMC environment, an outsourced part machining task is usually decomposed into a series of process machining tasks, so

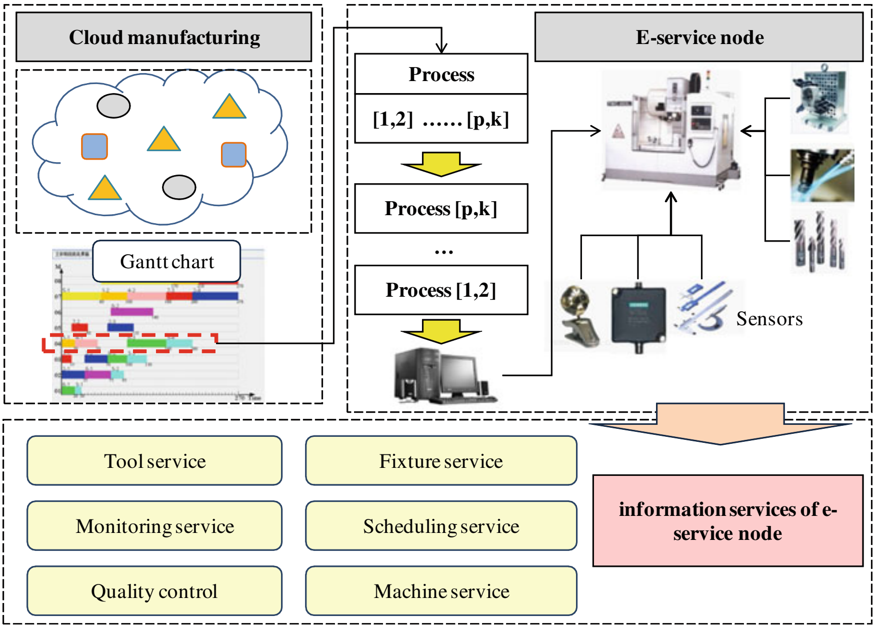

Fig. 3.14 The framework and workflow of the e-service node model

as to search in the MR pool and match the optimal MRs realizing the configuration of a virtual service-oriented machining workshop. As a machining device is encapsulated into an e-service node to monitor the single machining process round the device, an e-service node network is realized automatically when the virtual service-oriented machining workshop is generated to dynamically monitor the entire virtual workshop.

In other words, the retrieval and matching of e-service nodes and machining tasks are the key problems related to the generation of the virtual service-oriented machining workshop. From this point of view, an e-service node which is an encapsulation of a machining device and a series of sensors deployed to it can also be considered as a kind of MR too. It shows all the characteristics that a MR has, such as machining capability, production capability, etc. Besides, monitoring capability is also included.

3.3.3.3 Machining Tasks Monitoring Based on the E-Service Node Network

CMC is a collaborative platform of many enterprises that integrate abundant socialized machining resources to fulfill kinds of outsourced machining tasks. Because lots of the machining tasks are carried out in the platform simultaneously, the monitoring of each task is of great importance for the running of the CMC platform. The generated e-service node network provides great support to the monitoring process. It can be divided into three aspects, that is, configuration of the monitoring environment, collection of real-time data and data processing based on Auto-ID computing.

The configuration of the monitoring environment based on e-service node is the basis of the monitoring process in the CMC platform. A monitoring framework should be established to conduct the configuration and tell which on-site data should be collected for further analyzing. According to the information of the needed data, the corresponding sensors are configured to the related machining devices respectively, such as RFID, location sensors, temperature sensor, etc. In addition, electronic tags are attached to machining devices, cutting tools, fixtures, workpieces, and other equipments. An EPC (Electronic Product Code) code is written into each tag as a unique identification of each object that it attached to. Finally, a monitoring system should also be established to connect all the e-service nodes in a virtual workshop based on an outsourced machining task to manage the monitoring procedures.

The collection of the real-time on-site data is the basis of the further data processing. According to the established monitoring framework, we can know clearly what kinds of data need to be collected. Then the monitoring system will order the corresponding sensors to collect the related data through event-driven mechanism or other mechanisms.

Actually, the collected real-time data is somehow littery and ruleless, and full of repetitive data. Therefore, further data processing should be conducted to fuse the similar data, wipe off the repetitive data, and transform the raw data into the needed information that could be used by the upper systems directly. Here, Auto-ID computing technology is widely employed in data processing.

By these three steps, the monitoring procedure towards a single machining task in the CMC environment can be finished. Through the processed information, the upper system can realize the real-time scheduling, visualized management, etc., which provide strong supports for closing the loop of adaptive decision making.

3.4 A Case Study

In order to demonstrate the feasibility and applicability of the proposed models and methods, in this section, a use case is studied through a CMC prototype software system that developed by the combination of Java and Flex language. In the case study, three machining devices are chosen as MRs that need to be virtualized and input into the existing MR pool, that is, a CNC (Computerized Numerical Control) lathe, a deep-hole drill and a floor-type milling & boring machine (as shown in Fig. 3.15a). Furthermore, a torque arm of an airplane undercarriage which needs to be finish-machined is chosen as an outsourced part machining task, described virtually and added into the MD pool (as shown in Fig. 3.15b).

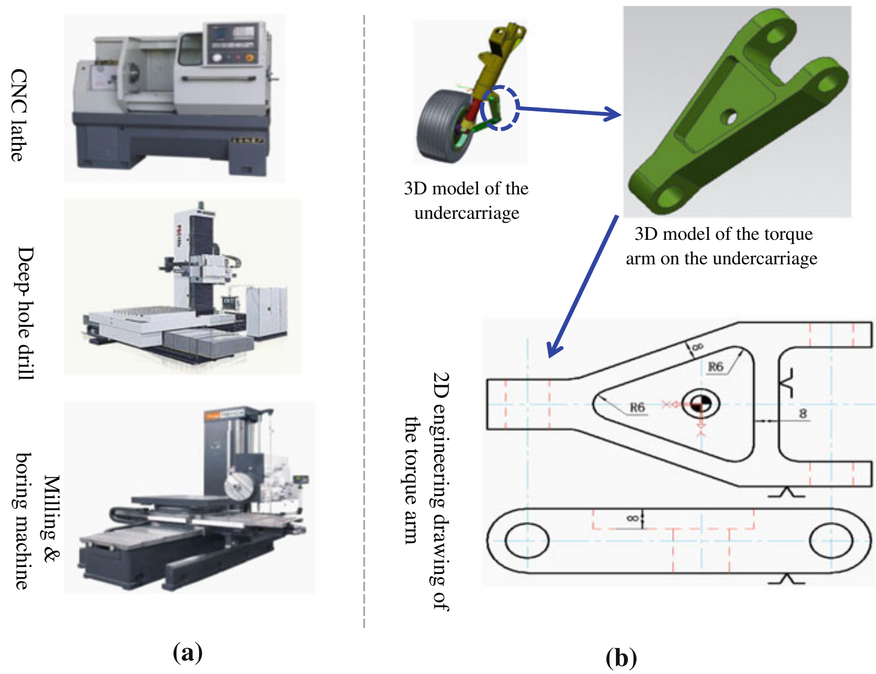

Fig. 3.15 The scenario of the use case. **a** Three machining devices. **b** A chosen outsourced part machining task

The running flow of the case study is clearly shown in Fig. 3.16. Firstly, one should create an account in the CMC system through the register service provided by the system. If he/she has already owned an account, he/she can directly login the system through the login service. It should be pointed out that when registering and logining the system, one should choose a corresponding role from the provided options, that is, platform side, service provider side and service provider side (as shown in Fig. 3.16a). An individual may have more than one role in this CMC system.

After choosing a role and logining into the CMC system, different desktops will appear according to the chosen role, and meanwhile, different applications and functions will be shown in these desktops as icon forms, as shown in Fig. 3.16b. For example, as a machining service provider, some important applications such as virtual access of MRs, order management, process monitoring, etc., are provided in the desktops. On the other hand, as a service requestor, the provided applications will cover functions likes description of outsourced machining tasks, trade, task management, task process monitoring, etc. CMC system also provides personalized designed desktops for different users. It means that one can add any of the applications provided in the application store to the desktop, and he can also delete any of the applications shown on the desktop to beautify he/her desktop.

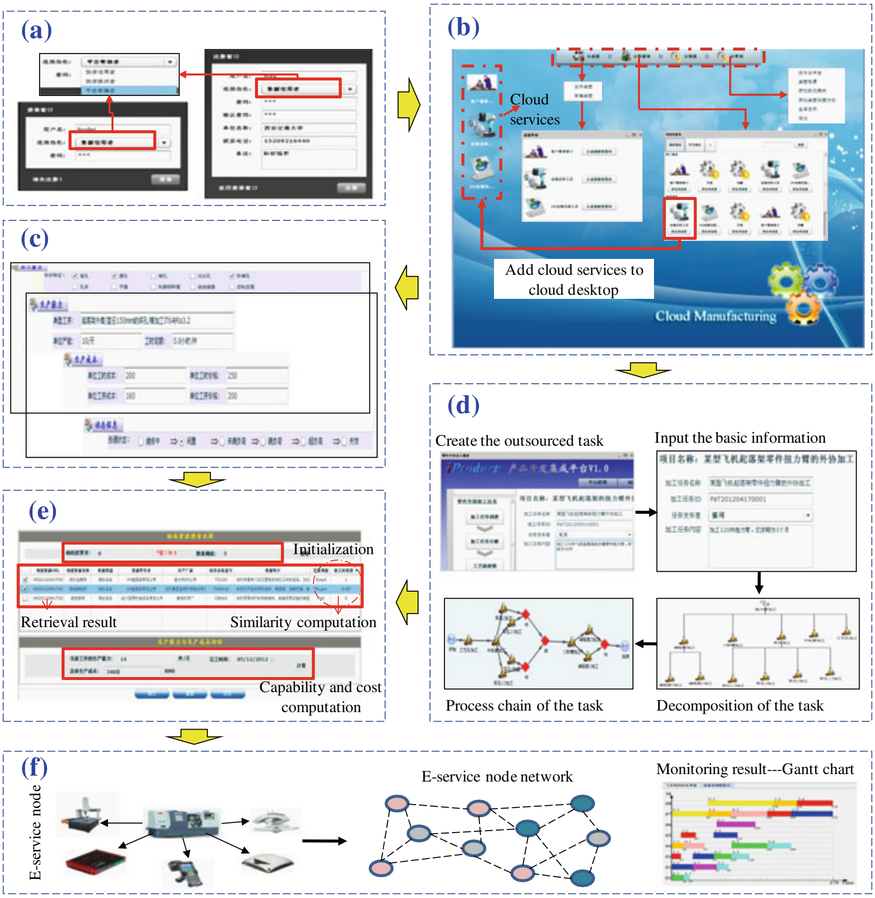

Fig. 3.16 The running flow of the case study. **a** Register and login. **b** Register and login. **c** Virtual access of MRs. **d** Description model of machining tasks. **e** Retrieval and matching. **f** Execution and monitoring

Figure 3.16c shows the virtual access of the three machining devices. Apparently, it belongs to the functions coming from the desktop of a machining service provider. Firstly, the service provider inputs his MR information into the CMC system through kinds of provided interfaces. Important information such as machining capabilities, production capabilities, cost and dynamic information, etc., should be covered in the input. Therefore, the three physical machining resources are modeled, and transformed into semantic descriptions which are stored in the MR pool for further retrieval and matching. Meanwhile, Fig. 3.16d shows the description model of the outsourced machining task (fashioning of a torque arm) so as to input the task into the MD pool. The task description model and process chain model are established. What's more, some important information such as batch, diversion and delivery date, etc., should also be covered in the input. This information is important and it describes what things need to be machined, when and how to be machined.

Then, the retrieval between MRs and the outsourced task that are conducted in the MR pool reason out the matching level of the two as shown in Fig. 3.16e. The evaluation of capabilities and costs are two of the most significant restrains that should be considered in the retrieval procedure. When the retrieval and matching procedures are finished, the chosen MRs, including physical devices and workshops, make up a virtual service-oriented machining workshop dynamically. Whereby, an e-service node network is generated additionally.

At last, when the outsourced machining task is being executed, the monitoring procedure is also being conducted at the same time by the generated e-service node network, which is shown in Fig. 3.16f.

3.5 Conclusion Remarks

This article proposes a cloud machining community (CMC) which mainly integrates the socialized machining resources (MRs) and deals with the outsourced tasks, including process machining tasks and part machining tasks. The ideas of cloud computing and service-oriented manufacturing are integrated together in the CMC system, through which, not only "*distributed resources are integrated to be used*" and "*integrated resources are distributed to be serviced*".

The operating mode and framework of CMC is established at first. Roles involved in it are divided into three classes, that is, platform side (cloud platform providers and platform technical providers), service provider side (machining service providers and logistics service providers) and service provider side (service requestors). Some important concepts, such as MR, so-MW, MR pool, machining community, etc., are defined to help to explain the CMC operating mode. What's more, logic flow of the CMC framework is also described in detail.

Then, several key enabling technologies are proposed. Virtual access of socialized MRs is the basic technology of the CMC, which transforms physical MRs into virtual ones and stores them in the MR pool. In this technology, capability model and formalized description of MRs (including machining devices and workshops) are established respectively, and the complexity analysis of the social manufacturing system is conducted too. Similar with the MRs, the technology broadcasting and contracting of outsourced tasks is also of great importance in CMC system. Firstly, the formalized descriptions of outsourced both process and part machining tasks are proposed respectively so as to input the information of these outsourced tasks. After that, models of pricing, trust and benefit distribution are proposed towards a single task, and the generation of virtual service-oriented machining workshops is declared to deal with all the outsourced tasks. The last enabling technology is machining procedure monitoring towards a specific outsourced task when the task is being fulfilled in a virtual service-oriented machining workshop. A machining device and the related sensors that deployed around it are encapsulated into a so-called e-service node to collect the real-time on-site data and monitor the current state of the device. Then, these e-service nodes included in a virtual machining workshop gather together forming an e-service node network to monitor the state of the entire virtual workshop.

Finally, a CMC prototype system is established and a simple case of fashioning the deep holes of the outer cylinder of an undercarriage is studied through this system. It demonstrates the feasibility and applicability of the proposed models and methods.

Future research in this area will include the modification of the proposed framework of the CMC to make it much more stable. In addition, the retrieval and matching algorithms need to be improved to enhance the efficiency too.

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Chapter 4
Factors Affecting Cloud Technology Adoption: Potential User's Perspective

Nicholas A. Ogunde and Jörn Mehnen

Abstract The idea that drives Cloud technology shows great opportunities that can be exploited by an organization. However, with such opportunities come some challenges and factors that have to be put into consideration. Knowing and understanding these factors make an organization better prepared for adopting the technology. A number of factors have been suspected to affect organization's adoption of Cloud technology. The purpose of this chapter is to confirm which factors actually do affect adoption of the technology. Inspired by the Technology Acceptance Model (TAM) and an extensive literature review, a working hypothesis of the list of factors that have potentials to affect Cloud technology adoption was developed. These factors were then assessed by a randomly selected sample of 47 working professionals in the United Kingdom through an online questionnaire. Analysis of the result shows that Security, Cost, Service Availability, Compliance and Perceived Usefulness are factors of concern that organizations would have to deeply consider before moving to the Cloud. It also shows that majority of professionals are already aware and substantially educated about cloud technology and believe they will find the technology easy to learn and use. They also recommend it to organizations.

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4.1 Introduction

4.1.1 Motivation

The underpinning idea behind the Cloud technology in general and Cloud computing in particular have been considered by not a few to be the new IT paradigm. Yet others believe that the phrase is an over-stretched word. With the volume of recent research and white papers on the topic however, it can be considered a hot issue. There have been forecasts that the technology has not only taken the IT world by storm, but perhaps is here to stay. According to Armbrust et al. [1], Cloud technology has changed the face of commercial IT, ensuring that computing services can be treated like a utility—much like water and electricity. Indeed it has been said that many people are already using cloud technology in different forms without even realizing it. This for example include things like using the free Yahoo and Google email, using online file storage by storing files e.g., music over the internet, watching recorded training seminars that are stored online, the list goes on and on. If the technology advance as expected, it has good possibility of changing the IT and business landscape as we have come to know it today.

4.1.2 Background

Gartner in 2009 estimated the value of cloud services revenue to surpass \$56.3 billion, a 21.3 % increase from 2008 revenue of \$46.4 billion [2]. It is also forecasted that the market will reach \$150.1 billion in 2013. This upward growth can of course only continue if many businesses and organizations are and remain comfortable with cloud computing as a solution that improves productivity. Cloud technology is a way to improve productivity, it has to be accepted and used by employees in organizations [3].

Several models have been posited to explain factors that affect the user acceptance of a technology [3–6]. One such model, the Technology Acceptance Model (TAM) posits that two beliefs, the perceived usefulness and the perceived ease of use are of essential importance to a user's adoption of technology [4]. It defines the perceived usefulness as the subjective probability of a user that a particular solution will enhance his productivity in an organization and the perceived ease of use as the degree to which the user thinks the solution will be without fault. The model has been used in many research works with great success [7, 8] and has been extended by a number of authors to include other factors. These works have greatly influenced this research work.

While there have been many papers and research work into Cloud computing and some on the benefit it offers, there has not really been much work done in actually analyzing the opportunities and the challenges the innovation offers from the customer and user point of view. This research work addresses this challenge.

It reviews cloud adoption and the factors that enhances or inhibits it, but carries out the research work from the perspective of the would-be customers and users of the solution. The result of the research should be able to assist decision makers in understanding what the average computer users and employees consider as pitfalls and benefits of using the Cloud as a solution.

4.2 Literature Overview

4.2.1 Introduction to Cloud Computing

Cloud computing has been regarded as a new technology trend that is expected to shape information technology process and the IT marketplace [9]. However, while not denying the obvious advantages that are possible with the implementation, several academic writers [10, 11] fail to see it as a new technology. To them, it is just a natural progression in the demand of information technology services and products and is based on already existing technological concept like grid computing, virtualization and service oriented architecture [10].

4.2.1.1 What is Cloud Computing?

Cloud computing is considered a phrase that has been quite difficult to define with. Qian et al. [12] described it as one of the vaguest technical terminology in history. According to them, this is because the phrase is applicable in so many application scenarios coupled with the fact that so many organizations have hyped up the phrase to mean more that it is supposed to Adamov and Erguvan [13] also described it as a word that is misused a lot. Indeed, not a few definitions exist for the phrase.

According to the U.S. government's National Institute of Standards and Technology (NIST), Cloud computing can be defined as everywhere, easy and on-demand access to a shared pool of resources (including networks, servers, storage, applications) over the network with zero or minimal interaction with or involvement of the service providers. On the other hand, Buyya et al. [14] described it as using infrastructure as a sort of "Cloud" where users and organizations are allowed to access applications and services on demand, no matter where they are located. Infrastructure here represents huge data centre that are monitored and managed by a service provider. He goes on to define Cloud as "a type of parallel and distributed system consisting of a collection of inter-connected and virtualized computers that are dynamically provisioned and presented as one or more unified computing resource(s) based on service-level agreements established through negotiation between the service provider and consumers".

Cloud computing introduces three new concept to the term infrastructure [1]. These are:

- The impression that computing resource is infinite and so users do not need to plan much ahead for over utilization,
- The fact that organizations do not need to commit themselves to particular resource utilization. They can simply start small and upgrade as the need arises,
- The ability to pay for only the resources they have used, with the option to upgrade at any stage of utilization and downgrade after use of computing resources.

With Cloud technology organizations are able to host their applications or data with a Cloud service provider, access it from anywhere (using a browser) and pay for just the computing facilities they use much like a household will pay for the use of a utility.

4.2.1.2 Types of Clouds

In literature one distinguished typically three types of Clouds:

Private Cloud This is a Cloud environment that is built on a private network, with the organization having control over data, security and quality of service. Usually, this kind of cloud is built for the use of an organization and can be managed by the organization's IT.

Public Cloud This kind of cloud is usually managed and hosted by a third party cloud service provider with computing resources being dynamically provisioned over the internet using web applications or web browsers.

Hybrid Cloud This is made up of a combination of private and public Clouds. Here, part of the applications of an organization runs on a private cloud, while the other services are provisioned over the public Cloud [15].

4.2.1.3 Cloud Computing Architecture

According to Zhang et al. [16], Cloud architecture can be considered to be made up of the four layers that are closely knitted together to deliver the hosting service. These are listed below:

The Hardware/Data centre layer This consists of the physical resources of the cloud including things like servers, routers, switches etc. It is usually made of aggregated resources that are organized to function as a single fault tolerant resource.

The infrastructure layer This is also called the virtualization layer and is where the pool of necessary computing resources is deployed. The layer makes use of virtualization technologies such as that of VMware®. This layer is important and is used for dynamic service provisioning.

The platform layer This layer resides on the infrastructure layer and consists of the operating systems and the application frameworks. This layer operates to remove the burden of deploying applications to the VMware® containers.

The application layer These are the applications that actually provide the services offered by the cloud and are located at the top layer. These applications have the ability to automatically scale to performance.

4.2.1.4 Cloud Computing Service Types

Cloud computing services can be categorized into three types. They are explained below:

Infrastructure as a Service (IaaS) This refers to computing resources with guaranteed processing power and storage abilities being offered as a service usually in the form of virtual machines. An example of this service is the Amazon Elastic Compute Cloud (EC2).

Platform as a Service (PaaS) This refers to providing operating system and the accompanying resources that are necessary to use applications. In short one can consider this as an IaaS with a software installed already. An example is the Microsoft Azure and Google AppEngine.

Software as a Service (SaaS) This is providing a specific application as an on demand service. An example is the Google apps [15].

4.2.1.5 Major Cloud Services by Providers

Amazon Elastic Cloud Compute (EC2), one of the most common Cloud computing platforms adopted by organizations, allow an organization to use web services interface to provision different types of operating systems and load them with as much customized applications as desired [17]. Alternatively, the organization has the option of using one of the already built and customized Amazon virtual Images (AMI) with software based on needs. The solution allows capacity to be configured with minimal effort, provides adequate control of technology resources and offers the added advantage of only paying for capacity per hour with no long term commitment. Another Amazon cloud service is the Amazon Simple Storage Service (Amazon S3). It provides a web interface to store and retrieve large volume of data at any time and from anywhere with capacity up to 5 Terabytes [18]. Prices are charged per data transfer, based on location of you "Amazon bucket" which is the region you have chosen to domicile your data.

Google App Engine [19] offers opportunity to run applications on Google's computing infrastructure. Applications can be built using standard java technologies or any other language using a JVM based interpreter or converter. A dedicated native python runtime environment is also provided. Application can be published to be shared with the whole world or restricted to users of the organization. A web page administration console is also provided to the users for managing the applications. Google offers free 500 mb of storage with enough CPU capacity to support about five million page hits per month for the engine which can be upgraded to raise the limit.

Windows Azure and SQL Azure provide an opportunity to host applications on Microsoft computing infrastructure while using a host of developer services to build applications. It supports an extensive selection of proprietary development tools and protocols including Live Services, Microsoft .NET services, Microsoft SQL services, Microsoft SharePoint services and Microsoft Dynamics CRM services. There is also opportunity to interface with non-Microsoft technologies using support for web API's such as SOAP and REST [11].

Other Cloud computing services providers includes Salesforce.com, IBM and EMC. However, these are not as prominent as the three already discussed above.

4.2.2 Cloud Technology Adoption

Adoption according to [20] can be defined as "the acceptance and continued use of a product, service or an idea". Despite the much talked about prospects of Cloud technology and the potential that the innovation offers for IT commercialization, several potential cloud users are in fact yet to opt for the solution [21].

According to Chow et al. [21], even most of the organizations that have implemented the solution have only just tested the waters in managing to put non business critical application on the cloud. This is largely due to the fact that they do not completely trust the solution as yet. This position was supported by Kim [22] that Cloud computing still has lots of issues that are preventing its adoption by majority of users. He mentioned compliance as a peculiar challenge for corporate organizations. However, a Cloud technology adoption survey carried out by Mimecast in 2009 to examine the perception and adoption of Cloud computing solutions among 565 respondents across US and Canada seems to confirm an interesting position [23]. According to this survey, 60 % of respondents seem to favor adoption of the solution, with 70 % of those already using the solution intending to further move additional applications to the cloud. This obviously indicates that those organizations feel they are realizing appropriate benefit from the implementation of this solution.

On the contrary, another research work by Behrend et al. [24] seem to confirm that adoption of the Cloud idea is still plagued with inherent issues that needs addressing before users can find the innovation comfortable to use. The research work investigated the adoption and usage of the Cloud by a community college in south eastern USA comprising of approximately 750 students. It further explained that Cloud computing is like any other IT initiative and its adoption is plagued by technical factors of the solution, characteristics of the organization that introduces the solution and the response of individuals within the establishment to the new tools introduced by the solution.

Yet, others like Greenwood et al. [25] believe that it is highly unlikely that any organization will totally host all its applications on the cloud. They believe that most environments of organizations that adopt Cloud computing will be heterogeneous—consisting of some applications hosted in the Cloud (possibly more than one cloud providers) and other hosted on dedicated servers within the organizations.

A number of factors have been reviewed by several authors and writers to affect the adoption of Cloud technology, some inhibiting the adoption rate and yet others serving as a motivation.

Cost

One such proposed factor that has been considered to affect Cloud adoption is the cost. According to Skilton [26], Cloud computing is able to help business and drive cost savings by helping an organization to "avoid the cost of over-provisioning and under-provisioning" of computing resources. Of course this is supposed to be in addition to the business advantages enabled by low entry cost since the organization will not have to invest in buying IT assets. Khajeh-Hosseini et al. [27] also stated that one of the reason consumers move to the cloud is for lower IT support costs.

This position is also supported by the research work of Khajeh-Hosseini [28] while looking at the migration of an Enterprise IT to IaaS. They discovered that moving to the cloud has clear financial benefits to the organization to the tune of almost 37 %.

However, Leavitt [29] thinks that while it is indeed possible that organizations save money on equipment and software, such money may be offset by investment on bandwidth, which is a critical cloud operation dependency, especially if large data is concerned. Kondo et al. [30] in his research work also seems to think that Cloud computing is effective only for small and medium sized applications, but that for large projects; the costs are simply too much. In fact, Misra and Mondal [31] confirmed that opinions on opportunities for cost savings in quite divergent on many blogs with one group confirming that the solution is economically profitable while others are saying is quite more expensive.

Security

Security is another major factor that has been said to affect Cloud adoption [21]. According to them, this is the major reason why potential cloud users have not joined the cloud, and those that have, are just testing the waters with non-sensitive business data. This position was also supported by the cloud services user survey carried out by IDC exchange [32], which listed security concerns as the number one major issue. The concerns here include the privacy of the hosted data and whether the cloud provider will be able to provide the relevant level of audit needed by the organization. With their data out of their control, it says most organizations worry if they are not more vulnerable to attackers.

On the contrary, Alecu [33] believed that implementing Cloud technology has obvious advantages to an organization. Cloud providers are better able to effectively manage and use available resources to better secure data in their premises than a single organization would. They are for example able to provide centralized data storage, adequate monitoring of data access and adequate logging. Grossman [34] supported this claim by saying that the economy of scale with which most Cloud computing operates gives them the necessary resources to implement adequate security. Assuncao et al. [35] also said that Cloud computing being based on a virtualized technology offers increased security through creation sandboxes for running applications with unquestionable reliability. According to Youseff et al. [36] however, security is still a major issue that Cloud computing users would have to contend with before a decision to move to the cloud.

Availability

Another factor with potential to affect Cloud adoption is system availability [36] Availability as used here covers reliability issues, latency issues and performance issues. According to Youseff et al. [36], outage is one problem that users and cloud providers will have to battle with in the light of possible network outage and system failures. The effect of this is actually managed by putting an appropriate Service Level Agreement (SLA) in place between the users and the providers. Kim et al. [22] also pointed out that outages may be permanent or temporary, with a permanent outage implying that a company has gone out of business. This has happened before and is inevitable. Kim believes that a company should exercise discretion in the data they put on the cloud and should endeavor to make backups.

Harish and Dhanasehar [37] agreed with this stating that an organization that decides to move to the cloud will have no option but to totally trust on the availability offered by the cloud provider. The only way this trust can be earned is for a cloud provider to standardize their SLA. Clouds have also been said to suffer from a high level availability which Vaquero et al. [38] believes is as a result of the lower level of maturity of the paradigm.

However, Youseff et al. [36] did not fail to quickly point out that even though availability issue is not uncommon with cloud, most cloud infrastructures are built to provider high availability guarantees. A user can even drastically increase this by blending a mix of cloud offerings i.e., combining a Google app engine with an Amazon s3 service.

User awareness

User awareness and education is also another factor that has been noted to affect Technology usage, and indeed Cloud adoption. According to Rogers and Shoemaker [39], the acceptance or rejection of a technological innovation actually begins when users become aware of that product or innovation. In an independent research work carried out by Sathye [20] to discover factors affecting the adoption of Internet banking as a technology innovation, he discovered that user awareness of the product and the benefit it offers play a major role in users deciding whether or not to adopt the solution.

If users are not keen to adopting the Cloud as a solution, it may be perhaps because they are not aware of the solution or the benefit that adopting the solution has to offer. This position was also supported by the work of Beloglazov et al. [40]

that user awareness is one factor that cannot be ignored when it comes to usage of Information technology and innovations like the Cloud. The more aware users are of Cloud computing and its benefits, the more inclined they are to use the resources.

Perceived ease of use and perceived usefulness

Another well acclaimed factor that affects adoption of technological innovations and can well affect adoption of Cloud technology is the perceived ease of use and the perceived usefulness of the innovation. This theory was first pioneered by the research work of Davis [4] and has been confirmed by several other researches. He defined perceived ease of use as the extent to which the use of a particular product is believed to be free of effort and perceived usefulness as the degree of the belief that a particular tool or product will enhance the performance of a job. In a different research work by Grandon and Pearson [41], these factors were also established to have significant effect on the adoption of Electronic commerce.

A research work by Fenech [42] on the other hand did not seem to confirm that the two factors have a direct influence on the rate of adoption of the World Wide Web. He indicated that computer self-efficacy on the other hand seems to be a major determinant for the adoption. Self-efficacy, according to Marakas et al. [43] cited in Yi and Hwang [44] defined computer efficacy as an individual's judgement of his efficiency to adequately use the computer hardware and the applications that are installed on the device to achieve set objectives. Nonetheless, the research work of Behrend et al. [24] seems to unequivocally confirm that these two factors play a major role in Cloud adoption and usage in community colleges.

Compliance

Compliance is another major issue faced by organizations moving to the Cloud [45] and therefore has a great potential to affect adoption rate. According to Subashini and Kavitha [45], this is because most customers may not have control over where their data is actually located and hence fear falling short of regulatory and data privacy laws. As an example, certain data types are not allowed to leave the countries in many EU and American countries. Most enterprises in the US are bound by regulations concerning storage, disclosure and privacy of data. This for example includes Serbanes-Oxley Act and HIPAA [22]. According to Kim et al. [22], Consumers need to comply with these regulations even in their use of Cloud computing.

Supporting this argument, Chow et al. [21] reiterated that while the legal consequence of application and data hosting in the cloud is still far from being clearly understood, there is obvious "potential lack of control and transparency when a third party holds the data". This, according to them is affecting organizations' desire to move to public clouds. Most of them rather prefer to build private Clouds for themselves so that they can still partake of the benefits of the solution.

Vendor lock-in

Vendor/data lock-in has also been regarded as a factor that affects adoption of Cloud technology [46, 47]. Software stack has increased interoperability among platforms, but the API used in Cloud computing is still essentially proprietary and so difficulty exists for an organization to extract out its data should a reason demand so. As more cloud providers emerge, portability (ability to extract data) is increasingly becoming a more important criterion [29]. As it is, if an organization is not happy with the services of a provider, they cannot easily and inexpensively transfer a service to another provider or copy data back to in-house. A rework or reformat of the data is usually necessary. While this position is welcome to cloud providers, it is a menace to consumers. Armbrust et al. [1] also criticized this situation proposing that the solution is to standardize the APIs that are used by Cloud computing providers.

4.3 Survey

The qualitative research work for this chapter was carried out using a survey. Surveys are quite widely used and can generate large quantity of standardized data and information for quantitative study and hypothesis testing. Surveys use methodical sampling questionnaires to measure the characteristics of the population with statistical precision [48].

The online version of questionnaire is the chosen form of survey used in this research work to collect the data used for analysis. It has the advantage of; being inexpensive, not requiring too much interviewing time, easy to analyze and also allowing respondents to maintain their secrecy to deeply consider their response. On the downside, response rate can be low and it may take quite a while to get reasonable number of responses.

4.3.1 Questionnaire Design

Based on the literature review focused on the factors affecting Cloud technology adoption, a questionnaire was designed. The questionnaire consisted of three parts; organization, Cloud computing questions and demographics. Before the final copy was agreed, draft copies were circulated to a couple of known experts in the field of Cloud technology as recommended by Rattray [49]. Their recommendations and input were taken into consideration to ensure that the questions asked were relevant. The questions were also sufficiently reviewed to ensure that it is clearly worded and not biased or leading in any shape or form. Best practices such as; asking easier questions first, grouping similar questions and avoiding use of abbreviations were also adhered to. While two questions were single item response, a number of the questions were multi-item scales to avoid bias, misinterpretation and reduce measurement error [50].

Likert-type questions account for majority of the questions and have been considered to be a relatively easy, efficient and appropriate method to use [49]. A free text response was also provided in a section to encourage richer data gathering by allowing respondents to provide alternatives to options provided. A copy of the questionnaire is shown in the Appendix.

4.3.2 Questionnaire Hosting

After design, the questionnaire was hosted on the World Wide Web so that it can be easily accessible to respondents using internet access. As the popularity of internet increases and the cost of computer hardware and software decreases, internet is becoming a fruitful area for conducting survey research [51]. Apart from the obvious advantages of cost and time savings, online surveys provide access to group of unique individuals which otherwise would be difficult to reach.

The online vehicle used to deliver the survey is Google Docs application. Google Docs is robust, free and allows data to be extracted into excel formats for different kind of analysis. There is no restriction on the number of respondents that can fill the survey, as compared to some other free survey tools. It also rides on Google's time tested infrastructure to provide adequate reliability in speed of access.

4.3.3 Questionnaire Circulation

After been made available online, the questionnaire link was then forwarded randomly to some 200 professionals in various organizations across the United Kingdom. In order to also increase the sampling frame, the link to the surveys was also posted to some selected Cloud forums. Care was taken to ensure that organizations of varying sizes were represented in the list of respondents selected so that results are not skewed in a particular direction.

It should be noted however, that because only the opinions of professionals are required, the survey was restricted to these groups of people. Respondents were also encouraged to help forward to other professionals that are known to them. Support was provided in form of emails assistance to people who had any difficulty with filling the survey.

4.3.4 Results Collection

At the end of the survey (which lasted about 10 days), the resulting information and data were extracted from the hosting location to a Microsoft excel format to be imported and analyzed with the Statistical package for Social Sciences (SPSS) V17 software. The resulted data were also pruned and styled to make it more presentable and compatible with the SPSS software used for the analysis. Care was taken not to modify any statistical data in the process.

4.4 Analysis and Discussion

4.4.1 Analysis

Of the estimated 200 professionals contacted to fill the survey, only 47 actually filled the survey forms. This represents a response rate of about 23.5 %. Data from the responses were then collected, verified for consistency and analyzed with SPSS Version 17. All the questionnaires were correctly filled and were considered valid.

4.4.1.1 Organization

The first part of the questionnaire focused on the profile of organizations represented in the survey. Small sized organizations represented 19 % of the survey response (13 % micro, and 6 % small) while just 4 % represented medium sized organizations. Large enterprises were most represented in the sample with a value of 77 %. Also, of the total number of respondents, only 14.9 % have no input to the kind of solution their organization adopts. 19.1 % are decision makers while 36.2 % recommend solutions to decision makers. A further 29.8 % have at least an input into the solution that their organization adopts. We could conclude that all categories of professionals were adequately represented by the survey. These data are represented in Fig. 4.1 (Table 4.1).

4.4.1.2 Demographics

The last part of the survey covered the demographics of the respondent. Majority of the respondents have work experience falling in the ranges 6–12 and 13–20 years represented by 37 and 28.3 % respectively. 23.9 % have experience ranged 21–30 while only 4.3 % have over 30 years work experience. Majority of the respondents fell between the ages 26–35 and 36–45 with 41 and 43 % respectively (Table 4.2).

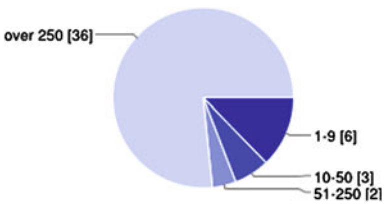

Fig. 4.1 Size of organizations represented

Table 4.1 Distribution of positions in the organization

Position	Frequency	Percentage
I am a decision maker	9	19.1
I recommend solutions to decision makers	17	36.2
I have input to choice of solution adopted	14	29.8
I have no input in choice of solution adopted	7	14.9
Total	47	100.0

Table 4.2 Work experience

Years	Frequency	Percentage
0–5	3	6.4
6–12	18	38.3
13–20	13	27.7
21–30	11	23.4
Over 30	2	4.3
Total	47	100.0

4.4.1.3 Cloud Technology Questions

According to the survey, a decisive 91 % said they will recommend Cloud technology to organizations. However, they differ on the type of Cloud option they would recommend. 52.8 % said they would recommend hybrid Cloud to organizations while a close 42.86 % decided to opt for private Clouds. Only 4.76 % decided in favor of public Cloud.

4.4.1.4 Factors Affecting Cloud Technology Adoption

User education and awareness

Analysis of the survey shows that all the respondents admitted to having heard about Cloud technology. This interesting result is also buttressed by the fact that 91 % of respondents regard themselves as at least somewhat familiar with the technology. As can be seen from the table, only 8.5 % consider themselves not to be familiar with the technology despite having heard about it. For the purpose of analysis, representing the various likert scales with continuous numbers (1 = not familiar, 2 = somewhat familiar, 3 = very familiar and 4 = expert), the mean of the distribution is 2.49 which can be considered close to the value 2 representing "somewhat familiar".

Service availability

At first glance, it was easily observed that a lot of respondents could not make out how service availability is affected by moving services to the cloud. This is easily inferred from the 46.8 % of respondents that neither agreed nor disagreed

Table 4.3 Familiarity with cloud technology

Familiarity	Frequency	Percentage
Not familiar	4	8.5
Somewhat familiar	18	38.3
Very familiar	23	48.9
Expert	2	4.3
Total	47	100.0

Table 4.4 Service availability

Service availability	Frequency	Percentage
Strongly disagree	1	2.1
Disagree	14	29.8
Neither agree nor disagree	22	46.8
Agree	8	17.0
Strongly agree	2	4.3
Total	47	100.0

Table 4.5 Vendor lock-in issues

Vendor lock-in issues	Frequency	Percentage
Strongly disagree	1	2.1
Disagree	5	10.6
Neither agree nor disagree	7	14.9
Agree	28	59.6
Strongly agree	6	12.8
Total	47	100.0

with the statement "organizations that move to the cloud are more likely to experience service availability issues". 29.8 % disagreed with the statement while 17 % agreed. Using continuous numbers to represent the various likert scales (i.e., 1 = strongly disagree and 5 = strongly agree), the mean value of 2.91 which is very close to the value 3 (neither agree nor disagree) confirmed the earlier statement (Tables 4.3 and 4.4).

Vendor lock-in

Analysis of the survey response confirmed that most respondents think that changing Cloud provider is an issue if an organization decides to go with Cloud technology. This is confirmed by the fact that a decisive 61 % of respondents agree with this statement. Only 11 % of respondent disagreed with the statement. Following the same representation as above, the mean value is 3.97 which is close to 4 (Agree) (Table 4.5).

Ease of use

The result of this survey confirmed that most respondents think that Cloud technology will be easy enough to learn and use. This was confirmed by 53.2 % of people disagreeing with the statement "Cloud technology will be difficult to learn and use". Interestingly, about 27.7 % neither agree nor disagree with the

Table 4.6 Ease of use

Ease of use	Frequency	Percentage
Strongly disagree	1	2.1
Disagree	25	53.2
Neither agree nor disagree	13	27.7
Agree	6	12.8
Strongly agree	2	4.3
Total	47	100.0

Table 4.7 Perceived usefulness

Perceived usefulness	Frequency	Percentage
Strongly disagree	3	6.4
Disagree	16	34.0
Neither agree nor disagree	12	25.5
Agree	13	27.7
Strongly agree	3	6.4
Total	47	100.0

statement. Representing the likert scales with numbers for analysis however, the mean is 2.61. This value is a little close to 3, which will suggest that even though the majority think Cloud technology will be easy to learn and use, the opinion can be considered quite close to neither agree or disagree (Table 4.6).

Perceived usefulness

While more people think that Cloud technology will enhance their productivity at their place of work (represented by the 34 % who disagree with the survey question), the statistics is not particularly skewed in any direction. In fact, a very close figure (27.7 %) agreed with the survey question. Representing the likert scales with numbers as usual and calculating the mean gives a value of 2.94 which is very close to 3 (representing Neither agree nor disagree) (Table 4.7).

Security

Analysis of responses show that majority of people agree that security exposure is an issue for an organization that moves to Cloud technology judging by the 68.1 % of people who at least agreed with the survey statement (42.6 % strongly agree and 25.5 % agree). This by far is the largest single value for strongly agree, showing that a number of people seems certain about this. Following the normal procedure of representing the likert scales with values from 1 to 5 to calculate the mean reveals a value of 3.87 which as expected is close to 4 (representing agree) (Table 4.8).

Compliance

Compliance is another area that seems respondents are sure is an area of issue with Cloud technology. 63.8 % of respondents seem to believe that there is danger of running afoul of compliance laws when moving services to the cloud. This contrasts with just 18 % who disagreed. As expected, the mean value is close to 4, an actual value of 3.72 suggesting that the average decision is that of agreement with the survey statement (Table 4.9).

Table 4.8 Security issues

Security issues	Frequency	Percentage
Strongly disagree	4	8.5
Disagree	3	6.4
Neither agree nor disagree	8	17.0
Agree	12	25.5
Strongly agree	20	42.6
Total	47	100.0

Table 4.9 Security issues

Security issues	Frequency	Percentage
Strongly disagree	1	2.1
Disagree	6	12.8
Neither agree nor disagree	10	21.3
Agree	18	38.3
Strongly agree	12	25.5
Total	47	100.0

Cost

It, however, seems a majority of the respondents are not exactly sure of the cost implications of Cloud technology and whether or not the solution will result in any cost savings. This is made evident by the fact that 46.8 % of the respondent neither agree nor disagree with the survey statement that "cost of Cloud computing can be prohibitive". 21.3 % disagree with the statement while 23.4 % agree. The mean value of 3.04 is rather close to 3 (Neither agree nor disagree) confirming the observation.

4.4.2 Further Analysis

An Analysis of Variance (ANOVA) test was carried out to see if there is any relationship between people's position in the organization and the various factors suggested to affect Cloud technology adoption. The resulting table is shown in the appendix. The analysis did show that position in organization do have statistical difference on familiarity with Cloud technology [F(3,47), $p = 0.01$] although the same cannot be said for others. Those who recommend solution are more familiar with Cloud computing (Mean = 3.00) than those who make input (Mean = 2.21) and those who make no input (Mean = 2.00) (Table 4.10).

To further analyze the pattern displayed here, a test called post hoc analysis was carried out. The test helps in finding patterns between variables that would otherwise remain detected. The type of post hoc test carried out was called Scheffe test (Table 4.1). This test showed that people who recommend solutions to decision makers are statistically different from those who have input and those who have no input to choice of solutions adopted. The size of variability predicted is 31.11 % ($\eta 2 = 31.11$).

Table 4.10 Cost issues

Cost issues	Frequency	Percentage
Strongly disagree	2	4.3
Disagree	10	21.3
Neither agree nor disagree	22	46.8
Agree	11	23.4
Strongly agree	2	4.3
Total	47	100.0

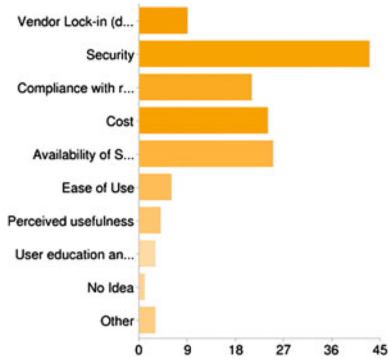

Fig. 4.2 The three *top* factors identified

The ANOVA test carried out to see if respondent's age range and years of work experience have a relationship with any of the factors did not yield any statistically significant result.

Also, the Spearman's correlation coefficient [52] was used to verify if there is any relationship between the factors affecting Cloud technology. The result is shown in the appendix. Most of the data at best only show very weak relationship, with the best being the relationship between ease of use and perceived productivity ($r = 0.393(47)$, p (two-tailed) < 0.05).

Figure 4.2 shows the bar chart for the three top factors that have been identified by respondents to consider when adopting Cloud technology. As can be seen from the chart, Security is the number one issue that respondents consider top priority. This is closely followed by availability of service and cost.

4.4.3 Discussion

This research work has established the factors considered by United Kingdom professionals to affect Cloud technology adoption. Generally speaking, the overall consensus of these professionals is that even though there are some challenges that still plague Cloud adoption, they will recommend it to organizations. This decision cuts across the various categories of professionals that exist in organizations (from decision makers to those who have no input to decisions) and could signify that challenges are not unexpected of a rather new innovation like Cloud computing.

Table 4.11 Post-hoc Scheffe test of familiarity with cloud technology and position

Position in organization	N	Subset for alpha = 0.05	
		1	2
I have no input in choice of solution adopted	7	2.00	
I have input to choice of solution adopted	14	2.21	2.21
I am a decision maker	9	2.33	2.33
I recommend solutions to decision makers	17		3.00
Sig.		0.680	0.050

Means for groups in homogeneous subsets are displayed
Uses Harmonic Mean Sample Size = 10.411

However, the type of Cloud technology preferred is the private Cloud or hybrid Cloud. This suggests that a number of people still feel more comfortable with having a big measure of control over their applications and services. This is even clearer as the overwhelming majority believed that security is a serious issue and is therefore a major factor that an organization would have to consider before moving its services to the cloud. This is in perfect agreement with the research work of Chow et al. [21]. Closely related to the issue of security is compliance with regulatory authorities. Clearly this is also another big worry for most professionals and is a big factor that needs to be addressed before an organization thinks of adopting Cloud technology. There can be dire consequences for organizations that find itself on the wrong side of the law (Table 4.11).

Perhaps one thing that has encouraged many people to look favorably on the adoption of Cloud technology is that an average professional is at least somewhat familiar with it and perhaps see it as the next phase of IT. As such, awareness and education is not really an issue with Cloud technology adoption. Interestingly, according to the research, people who recommend solutions are more familiar with the technology than all other categories. This is quite expected as such people often times are more knowledgeable about technologies as they often need to be able to defend their recommendations to managers. Conversely, people who make no input to decisions know the least about Cloud technology. In the same vein, learning and using Cloud technology will not be an issue according to the research. It may be that most people believe that its use would not be that different from the regular internet use they have become quite familiar with. To strongly support this, a lot of users now get the option to work flexibly from various locations and connect to applications located in their office. Perhaps Cloud use should not be any different from this.

It is a surprise though that even though Cloud technology is perceived to be easy to learn and to use, the average opinion on perceived usefulness is that of indifference. Clearly people do not have a clear understanding of how the use of Cloud technology can enhance their productivity at work and in fact whether it even will. This should be taken into consideration by an organization before deciding on compelling their employees to start using it. It is interesting to note though that a number of people think that Cloud technology will be easy to learn also think it will be quite useful to them. However, this relationship is quite weak and should not in any way be taken as the general opinion.

Another clear factor that has been established to affect Cloud technology adoption according to the research is vendor lock-in. The average opinion expressed is that moving into Cloud technology will be quite difficult if an organization does decide to opt for it. This opinion conforms largely to that of most writers and experts of Cloud technology who believe that there is no standardization in the programming interface used by Cloud providers [1, 29]. Hence organizations moving to the Cloud should ensure that they are aware of and make provisions for this.

The opinion on cost and service availability is quite similar to that of perceived productivity. The average opinion is that of uncertainty. Indeed most people are not sure if implementing Cloud will bring about any cost savings or even end up being more expensive. The same goes for availability. There is no clarity of whether opting for Cloud will improve or lower service availability. This is not too strange considering that even among the experts the opinion is quite divergent. These are huge areas that an organization should look into before dabbling into Cloud.

One interesting feedback from the survey is that ensuring a valid business case for Cloud technology adoption could be a potential factor worth considering.

Security has been deemed the most important factor that affects Cloud adoption, according to this research work. This is by no means a surprise. As hackers and attackers get more skilled and proficient in getting unauthorized access to applications and services, there is increased awareness of security. To host applications in the Cloud is to give away the sense of being responsible for the security of one's applications and services and is clearly not where most people want to be. As stated earlier, it explains why the choice of Cloud is largely private Cloud or at the most retaining sensitive data in-house and hosting non sensitive ones with Cloud providers (hybrid). The second and third most important factor highlighted is availability of service and cost respectively. These perhaps are considered quite important because of their sensitivity to the success of a business and the fact that most people are still not sure how the Cloud affects them.

This research work makes a necessary contribution. Even though a number of factors have been suspected to affect Cloud technology adoption, this study actually goes ahead to confirm which of these factors do actually need to be well considered when planning on moving applications to the Cloud.

4.5 Conclusions and Future Research

Cloud technology can be beneficial to an organization [1]. However, the organization needs to be aware of the challenges and factors like security, compliance, vendor lock-in, cost and service availability that can impede enjoying its benefit. These factors have to be clearly prepared for so an organization can continue to keep its cutting edge. Most professionals are already somewhat familiar with Cloud technology and believe that the technology will be easy to learn and use. They are also happy to recommend it to their organizations.

This research has some limitations that need to be highlighted. Firstly, the number of sample involved in this research is quite small compared to the working professionals in the United Kingdom. With more time and resources, the research work can be taken to a higher level. This is an area of further research.

Secondly, the research focuses only on the working professionals in the United Kingdom. It could be interesting, for example, to validate this result in another location, e.g., the United States. In addition, these factors need to be tested among a different category e.g., students who may be more technologically savvy than working professionals. This is also an area of future research.

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Chapter 5
Manufacturing Paradigm Shift Towards Better Sustainability

Z. M. Bi and Lihui Wang

Abstract A system paradigm is an abstract representation of the system; it is the system architecture that determines the types and numbers of the components and their relations in operation and interaction of the system. Its selection relies on customers' requirements and manufacturing environment. Many system paradigms have been proposed. However, most of them are based on an assumption that the life-cycle and boundary of a system can be defined based on the customers' requirements. Since sustainability becomes essential to today's manufacturing systems, a new concern is how to evolve existing paradigms to meet new challenges. The objectives of this chapter are, therefore, to examine the manufacturing requirements in a wider scope, to revisit existing paradigms to clarify the limitations and bottlenecks, and eventually to identify future research directions towards sustainable manufacturing. Within the context, this chapter focuses more on Reconfigurable and Cloud manufacturing system paradigms, and highlights the future endeavors towards better sustainability.

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5.1 Introduction

Manufacturing is the backbone of an industrialized society [1]. As always, it has been a cornerstone of the world's economy. Having a strong base of manufacturing is important to any country because it impels and stimulates all the other sectors of its economy. The most importance is that manufacturing creates wealth [2]. As the world's mightiest manufacturing economy, the United States produces 21 % of all goods made globally. Moreover, every dollar spent directly in manufacturing fosters another $1.40 in economic activity in other sectors of the economy. Manufacturing remains critical to a country's success in the global marketplace [3].

Humans are becoming more and more conscious about the deterioration of today's environment. Some buzz words such as global warming, pollution, shortage of oil, extinction of species have frequently been used in some headlines of news and major subjects of political disputations. Sustainability of economy, society and environment has been recognized as the priority to fundamental engineering research [4]. In manufacturing, many new terminologies related to system sustainability, such as environmentally conscious manufacturing, sustainable manufacturing, green manufacturing, remanufacturing, and sustainable productions, have been proposed [5]. However, the majority of the studies are limited to the general discussions of new requirements for next-generation manufacturing systems. The corresponding system paradigms for the implementation have not been studied systematically. Coincidently, with recent economic recession, research efforts on manufacturing paradigms have decreased significantly. Future research directions in this field are unclear [6, 7].

The objective of this work is to relate manufacturing sustainability to the next-generation system paradigms. To achieve this objective, a brief review is given in Sect. 5.2 on the importance of manufacturing and how the paradigms have been evolved in the dynamic environment. In Sect. 5.3, the concept of sustainability is discussed and a literature survey is conducted to understand the state-of-the-art in this area. Particularly, the studies on the matrices of sustainability are compared and summarized. The roles of manufacturing paradigms to sustainability are examined in Sect. 5.4, by mapping the functions of manufacturing paradigms to the matrices of sustainability; the missing connections between them are identified. Section 5.5 outlines future research endeavors and directions on reconfigurable manufacturing and Cloud manufacturing, and their advantages and limitations with regards to sustainability are explored. Finally in Sect. 5.6, conclusions and future works that lead to potential benefits of sustainability are provided.

5.2 Evolution of System Paradigms

The selection of a system paradigm relies on customers' requirements and the complexity of manufacturing environment. System complexity depends on the number of design variables and their dynamic behaviors with respect to time [8].

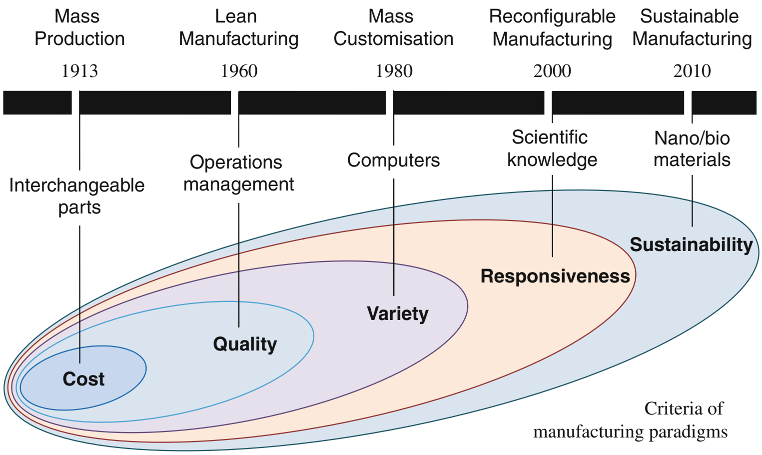

Fig. 5.1 Evolution of complexity of manufacturing systems (modified from [13])

Manufacturing systems have to be evolved to meet emerging needs from customers and the manufacturing environment.

Generally speaking, manufacturing systems become more and more complicated due to the expanded activities and the dynamics of manufacturing environment. The history of manufacturing has been reviewed by many researchers [9–13]. As summarized in Fig. 5.1, the scope of customers' requirements on products has been gradually expanded. The earlier markets before 1913 were short of products thus customers cared only about the functions; companies aimed at cost reduction to gain more profit. Since 1960, global manufacturing capabilities were sufficient enough to bring the competitions among suppliers; customers could demand more other than basic functions of products; therefore, how to improve product quality became the key strategy of success from 60 to 70s. With an abrupt advancement of information technology (IT) from 1980, the global manufacturing markets were gradually saturated, thus companies were pressured to manufacture new products at a fast pace to catch earlier marketing opportunities. Today, we are more conscious to the deterioration of the global living environment and the shortage of natural resources in the near future; manufacturing companies are forced to change their system paradigms to accommodate the needs for better sustainability. In Fig. 5.1, the evolution of manufacturing system paradigms has been divided into six phases. The symbolized concepts at each phase transition are *mass production*, *lean manufacturing*, *mass customization*, *reconfigurable manufacturing*, and *sustainable manufacturing*, respectively [2], e.g., 1913 was the year when manufacturing transited from craft production to *mass production*.

Numerous factors such as applicable strategies and technologies have their impact on the implementation of a new manufacturing paradigm. The success of a manufacturing paradigm can be viewed as the optimization of both hardware and software. It is helpful to relate companies' manufacturing objectives to existing theories and technologies [7]. Figure 5.2 depicts these relations. It consists of four

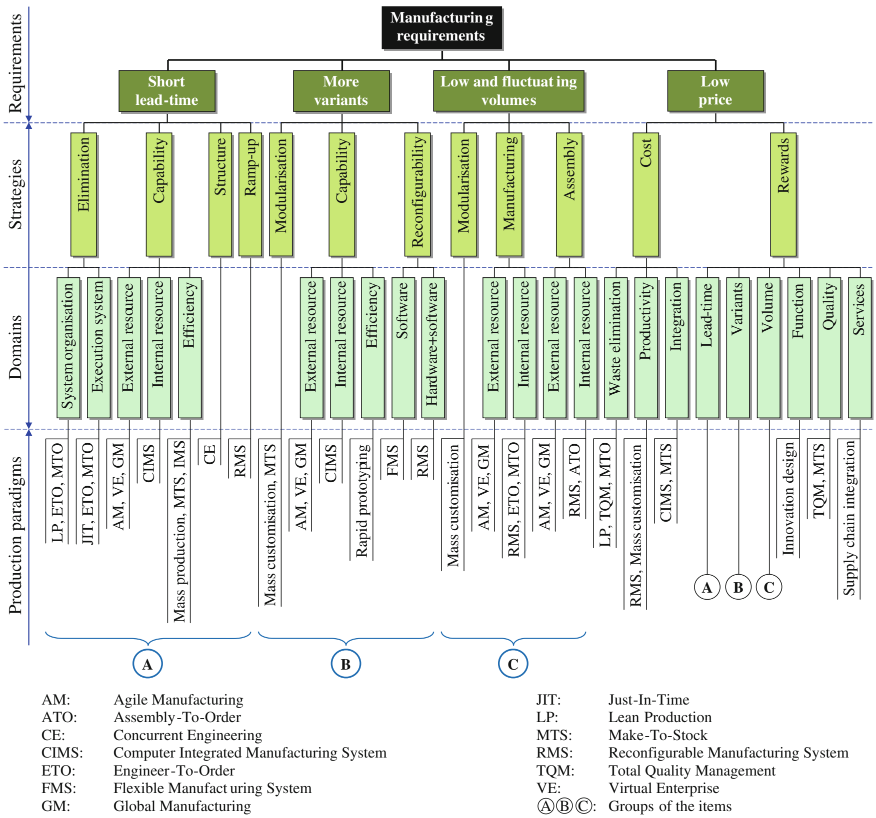

Fig. 5.2 Manufacturing requirements, strategies, domains and production paradigms

layers. At the first layer, four key manufacturing requirements are listed. At the second layer, the strategies for meeting these system requirements are shown. At the third layer, the domains of a manufacturing system, where the strategies are applied, are illustrated. At the fourth layer, various production paradigms are classified in terms of the applied strategies and domains.

Manufacturing system paradigms to date include *Lean Production, Just in Time, Concurrent Engineering, Flexible Manufacturing*, *Make-To-Stock, Make-To-Order, Engineer-To-Order, Assembly-To-Order, Agile Manufacturing*, *Virtual Enterprise*, *Computer Integrated Manufacturing System, Global Manufacturing*, *Reconfigurable Manufacturing System, Mass Customization, and Total Quality Management*. Many system paradigms, such as reconfigurable manufacturing and lean production, can meet the requirements in different ways since their implementations fit in different strategies. Moreover, it is challenging to tell that one paradigm is better than another without the consideration of unique situation of specific enterprise. All system paradigms have their strategies to meet certain requirements in one way or another, while none of them apply all strategies simultaneously to meet all requirements.

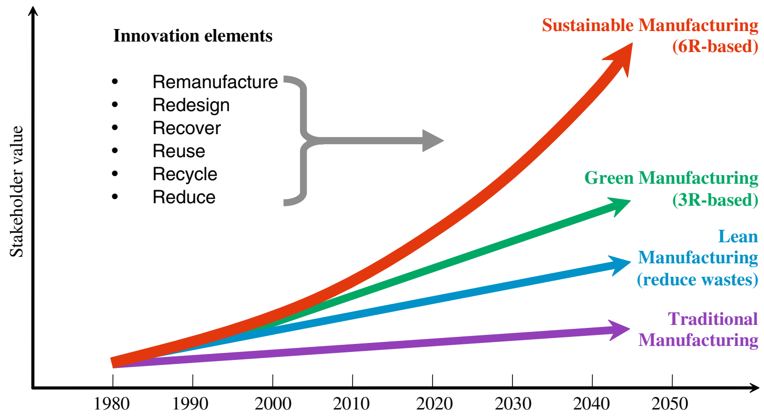

Fig. 5.3 Contributions of paradigms to stakeholder values (modified from [15])

It has been shown that existing system paradigms have been developed to meet the requirements of short lead-time, personalization (or more variants), low and fluctuating product volumes, and cost reduction. Their capabilities to deal with the requirements of sustainability have to be re-examined systematically. From the viewpoints of manufacturers, the limitations of the existing system paradigms to cope with sustainability requirements have been identified in [14]. It is now worth of exploring new system paradigms that can meet the sustainability requirements, effectively.

For most of the manufacturing systems, an essential condition for survival is to make profit through manufacturing activities. Eventually, the criteria of system design can be linked to the increased values of products from a manufacturing system. As shown in Fig. 5.3, the changing trends of system paradigms are predicted [15, 16]. It is suggested that a new system paradigm, i.e., sustainable manufacturing, will possess the capabilities of 6R (*reduce*, *recycle*, *reuse*, *recover*, *redesign*, and *remanufacture*) to maximize the increased value of products, whereas the green manufacturing is mainly capable of addressing the first 3R (*reduce*, *recycle*, and *reuse*).

5.3 Study on Sustainability

Today, the literature on sustainability is burgeoning [17]. The public perception of sustainability has been shaped by news and documentaries such as global warming, rising cost of energy, and the paucity of non-renewable resources [18]. There are five typical drivers for sustainability: (1) shortage of natural resources, (2) dramatic increase of world population, (3) global warming, (4) pollution, and (5) unstoppable global economy [19].

- **Shortage of natural resources**: Each American uses average 90,000 kWh of power annually, equivalent to 8,000 L of oil. The world consumes 75 million barrels of oil a day. With an estimation of 2 trillion barrels total oil reserves in the world, oil supplies are predicted to last another 40 years at the present production rate. For those manufacturers with energy intensive processes, energy prices have become a significant burden [20]. The similar problems happen to other natural resources such as coal, fresh water, and clean air. There has never been any debate about whether the resources available on the Earth are finite or not. What is being drawn more into focus now is that the rate of depletion of these resources is increasing as more countries move up the development curve [21].
- **Increase of population**: During the 20th century, the human population increased from less than 2 billion to over 6 billion people. The number of cities with more than 1 million people has grown from less than 20 to more than 300, in the last 75 years [22]. As the world population increases, more resources are consumed to satisfy the demand, leading to more wastes. In 1997, each person in USA produced a daily average of 2 kg of solid wastes, or approximately 163 million tons of municipal solid wastes that are eventually land filled. This figure could climb to 363 billion tons annually by 2030, which is enough to bury Los Angeles 100 m deep [23].
- **Global warming:** The United Nations has declared that the evidence of a warming trend is "unequivocal" and the human activities have very likely been the driving force on this change over the past 50 years [22]. Whether or not one agrees with the prediction about global warming, the generation of greenhouse gases, etc., it is clear that energy and resources of production are costly and the costs are likely to increase [24].
- **Pollutions**: Manufacturing generates over 60 % of annual non-hazardous waste; meanwhile, increasingly severe legislation demands a reduction in the environmental impacts of products and manufacturing processes [25]. The world is more crowded, more polluted, more urban, more ecologically stressed, and warmer than ever before in recorded history. Kaebernick and Kara [26] conducted a survey of industry practice around the world and shown that the companies acknowledge the importance of environmental issues. Today, between 80 and 90 % of companies rank environmental issues at fairly to very important. A recent survey of 1,000 US manufacturers has found that 90 % have environmental strategies and 80 % of them made environmental-friendly operations mechanisms [27].
- **Global economy**: As resources are getting harmful effect of wastes and pollutions are causing measurable negative impact on our living environment, the governments around the world are now actively involved in the development of products that not only are profitable and add values to the society, but also cause less damage to environment [28].

5.3.1 Definition

According to the US National Research Council, sustainability is defined as *the level of human consumption and activity, which can continue into the foreseeable future, so that the systems that provide goods and services to the humans, persist indefinitely* [28]; besides, emphasis on the interactions within and across different levels is critical to the fundamental understanding of sustainable design and manufacturing systems; because tackling any one of this issues alone can result in unintended consequences along other dimensions. *Sustainable manufacturing is developing technologies to transform materials without emission of greenhouse gases, use of non-renewable or toxic materials or generation of waste* [29]. Sustainable systems are characterized by interlinked interactions at various levels spanning economic, ecological and societal issues [30].

US Department of Commerce [31] defined sustainable manufacturing as *the creation of manufacturing products that use materials and processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound*. There is a need for the system as a whole to be sustainable. Jawahir and Badurdeen [32] clarified that sustainable manufacturing is not just manufacturing processes or the resulting manufactured products. To describe a sustainable system, a multi-level approach on products, processes, enterprise and supply chain need to be considered.

Besides, green manufacturing has been used as an alternative of sustainable manufacturing. "Green" technologies are often understood as those capable of meeting product design requirements while minimizing environmental impact. However, minimizing impacts is a necessary but not sufficient condition for a sustainability strategy. Three most important components of a sustainable manufacturing strategy are: (1) selection and application of appropriate metrics for measuring manufacturing sustainability, (2) completion of comprehensive, transparent, and repeatable life-cycle assessments, and (3) adjustment/optimization of the system to minimize environmental impacts and cost based on the chosen metrics and the LCA [33].

5.3.2 Current Situation

Consideration of sustainability in new product development is widely accepted, although not yet widely practiced. Current practices of product development in manufacturing companies are still predominantly based on traditional cost/profit models, aiming at achieving high quality of a product at low cost and high profit. The paradigm of product development towards low cost and high profit is unlikely to change significantly in the near future [34]. The prospects for sustainable manufacturing have been explored, including: (1) how manufacturers will respond the future challenges in the socio-economic business environment and technological change, (2) what the scope is for sustainable manufacturing assuming different socio-economic development paths, and (3) how the manufacturers will adapt their corporate sustainability strategies to these developments [35]. Existing researches on sustainable manufacturing are focused on the following aspects [36]:

- Metrics and analytical tools for assessing the impact of processes, systems and enterprises,
- Modeling of sustainable, environmentally conscious manufacturing systems and processes,
- Green supply chains,
- Manufacturing technologies for reduced impact, and
- Manufacturing technologies for producing advanced energy sources/storage.

5.3.3 Metrics of Sustainability

The role of metrics in engineering design and analysis cannot be overstated. Metrics serve as the “enabling technology” in design processes, especially from the vantage of achieving environmental sustainability through proper design [24]. A sustainable manufacturing strategy requires metrics for decision making at all levels of an enterprise. It is suggested to follow the framework of goal and scope definition. The distinction is made between environmental cost metrics and sustainability metrics [33]. Various standards, such as ISO 14000, ISO 14064, WEEE, RoHS, REACH, and ELV, have been developed in the last two decades. Kibira et al. [30] discussed the approaches by authorities to classify environmental policy procedures, which determine the incentives used to achieve compliance with environmental safety requirements, including regulatory instruments, market-based instruments, and information-based instruments. Dornfeld [36] suggested to measure sustainability in terms of gases emission (CO_2, methane CH_4, and N_2O), per capital, per GDP, per area/nation, recyclability, reuse of materials, energy consumption, pollution (air, water, land), ecological footprint—“fair share”, exergy (available energy) or other thermodynamic measures.

According to the definition of sustainable manufacturing [31], the activities in a manufacturing system can be classified into two types, i.e., activities on materials and activities on processes. As shown in Fig. 5.4, these activities have their impact on the living environment and on the society. The living environment has the aspects of ‘environmental impact’, ‘conserve energy’, and ‘natural resource’; whereas the society has the aspects of ‘customers’, ‘employee’, and ‘community’. Various criteria have been identified to evaluate the performances of a sustainable system paradigm.

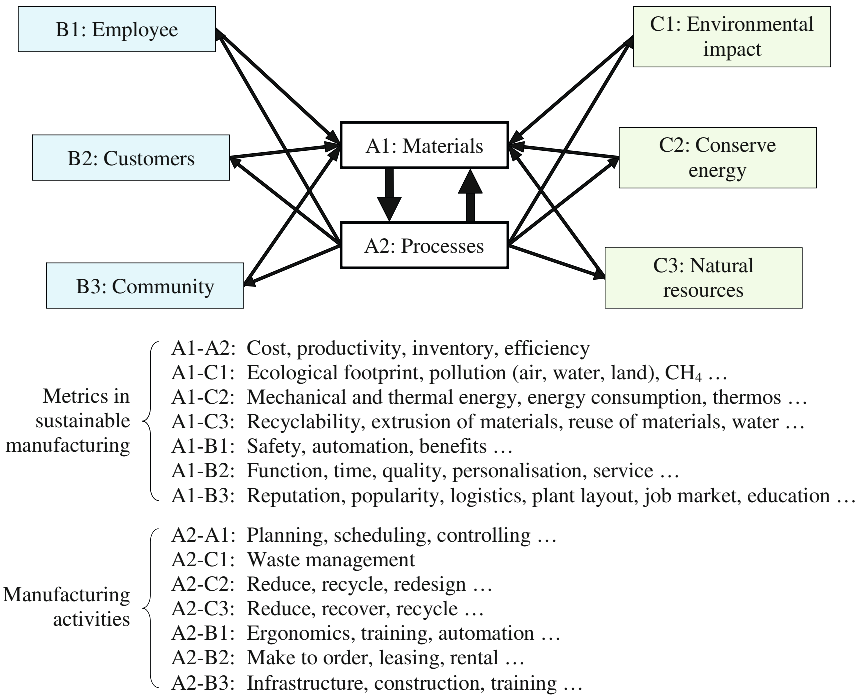

Fig. 5.4 Activities and metrics in manufacturing sustainability

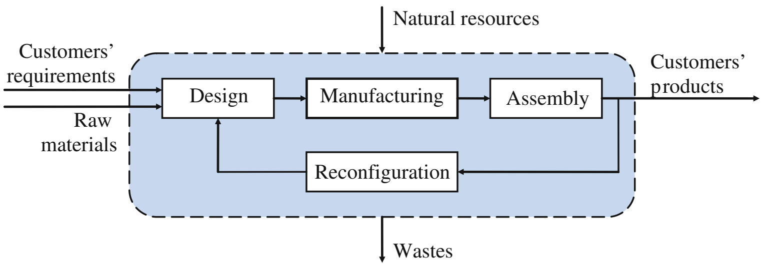

Fig. 5.5 A traditional manufacturing system

5.3.4 Roles of Manufacturing Systems for Sustainability

Recently, manufacturers have begun to realize the need for the responsible use and management of resources in the lifecycle of a manufactured product [37]. The roles of manufacturing systems to sustainability really rely on how the boundaries of a manufacturing system are defined.

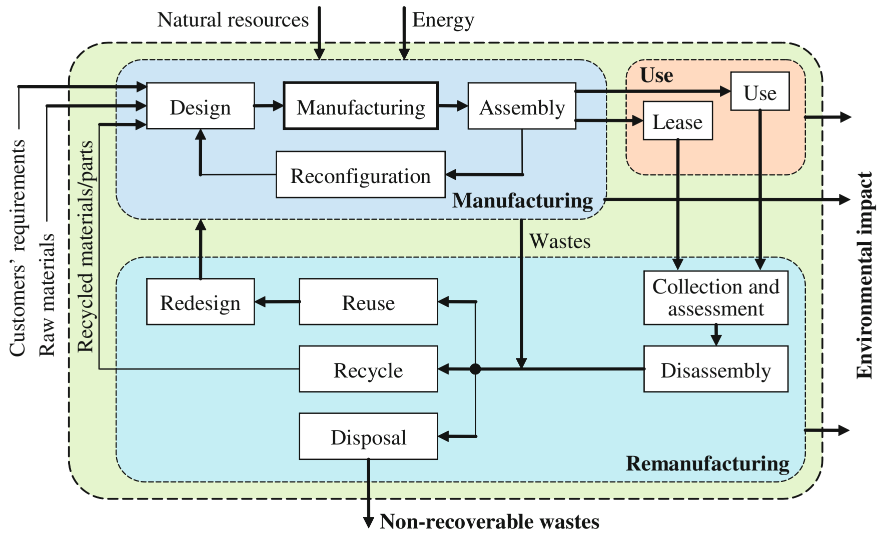

Fig. 5.6 A sustainable manufacturing system

As shown in Fig. 5.5, traditional manufacturing systems did not take into consideration of many factors such as waste management, pollution, recovery and reuse of used products. However, as depicted in Fig. 5.6, with the increasing conscious of environmental issues, many activities are introduced in the life-cycle of products. Manufacturers today have the choice of either including these activities in their operations and optimizing the overall structure based on the required tasks, or paying the cost for waste management and disposal etc. Therefore, the roles of a manufacturing system are dependable to the definition of a manufacturing system, and it varies from one company to another.

Jayal et al. [15] provided a case study to measure the contribution from manufacturing to overall sustainable manufacturing, revealing that the contribution from manufacturing has been estimated to be 25.7 %. As shown in Fig. 5.7, the sustainable eco-environment consists of three pillars, i.e. *environment, society and economy*. The phases in a product's lifecycle is divided into 'pre-manufacturing', 'manufacturing', 'use', and 'post-use'. The aspects of evaluation on the impact from the four phases are illustrated, and the overall impact has been accumulated. It has shown that the limited contribution to sustainability is from manufacturing sector. Similar portions of contributions are from the activities at the phases of 'pre-manufacturing', 'use', and 'post-use'. While sustainable manufacturing is extremely important to system sustainability, it is unrealistic to expect that a next-generation manufacturing paradigm can meet the requirements of sustainability completely.

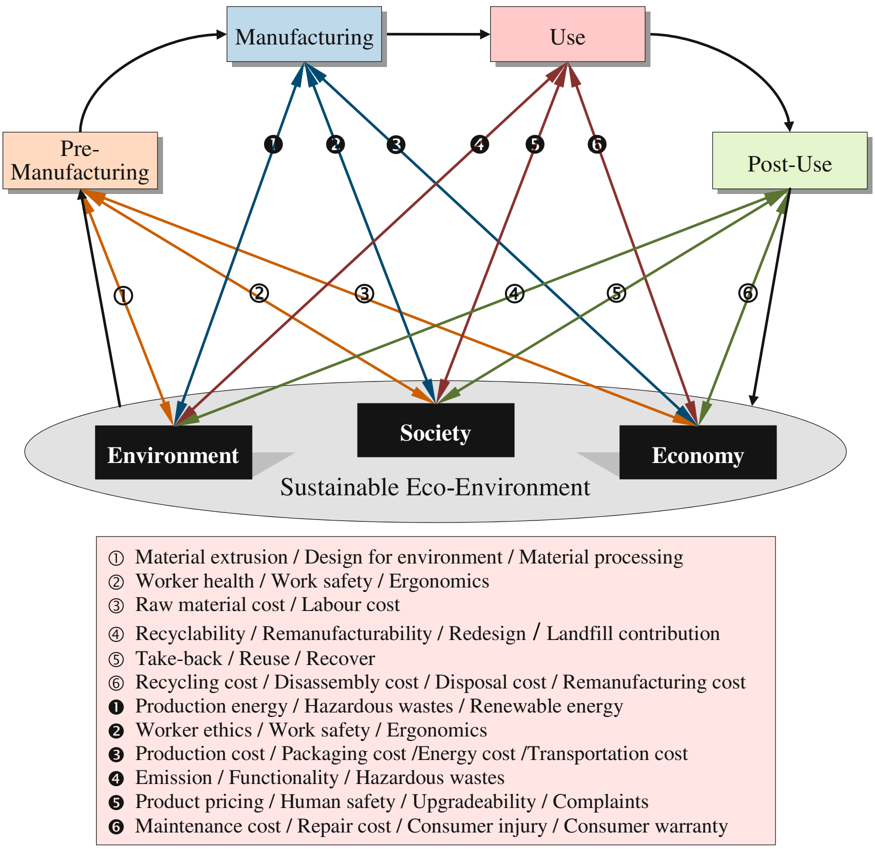

Fig. 5.7 Manufacturing contributions to sustainable environment

Another issue is the relation of sustainability and sustainable manufacturing. Although there are some overlapping between the design of sustainability and the design of sustainable manufacturing, it can be completely different according to the scope of a manufacturing defined in the figure. On one hand, a manufacturing system can be confined to one product with a limited consideration of product life time; the main difference from traditional manufacturing system is that some new criteria on waste management and environmental impact have to be taken into consideration in its design. On the other hand, an extreme case is to include all activities in one company; therefore, the design of a sustainable manufacturing system becomes design for sustainability. Note that when the boundaries of a system are considered, the inputs and outputs beyond system control have to be valued or devalued for the sake of system optimization, and this brings the uncertainties and fidelity of design results.

5.4 Reconfigurability and Sustainability in Cloud Manufacturing

5.4.1 From Reconfigurable Manufacturing to Sustainable Manufacturing

A clear definition of system boundaries is essential to determine an appropriate system paradigm. As illustrated in Fig. 5.2, existing system paradigms have been developed to meet the design criteria of cost, quality, personalization, and time. Since sustainability has become a new dimension to evaluate a manufacturing system paradigm, it is worth of examining the gaps of the desired performances of a system paradigm and the requirements of sustainability. From the perspective of the authors, reconfigurable manufacturing system (RMS) paradigm is one of the most advanced paradigms to deal with all of the requirements of today's manufacturing. In this section, RMS is used as an example to examine the gaps.

In an RMS, its system reconfigurability can be classified in terms of the levels where the reconfigurable actions are taken. Reconfigurability at lower levels is mainly achieved by changing hardware resources, and reconfigurability at the higher levels is mainly achieved by changing software resources and/or by choosing alternative methods or organizations. The resources at all levels must work together so that system reconfigurability can be maximized, cost-effectively. As shown in Fig. 5.8, an RMS basically consists of a reconfigurable hardware system and a reconfigurable software system. The hardware system includes *reconfigurable machining system*, *reconfigurable fixturing system*, *reconfigurable assembly system* and *reconfigurable material-handling system* [7]. The characteristics of such an RMS primarily include *modularity*, *scalability*, *integrability*, *convertibility*, and *diagnosability* [12].

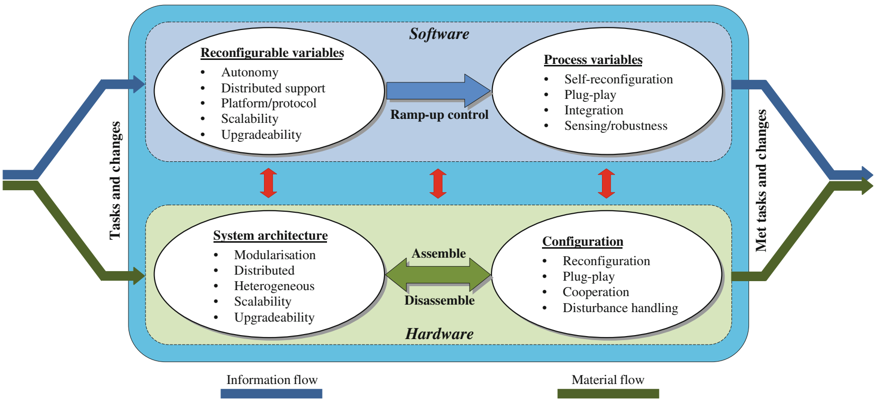

Fig. 5.8 Hardware and software in an RMS

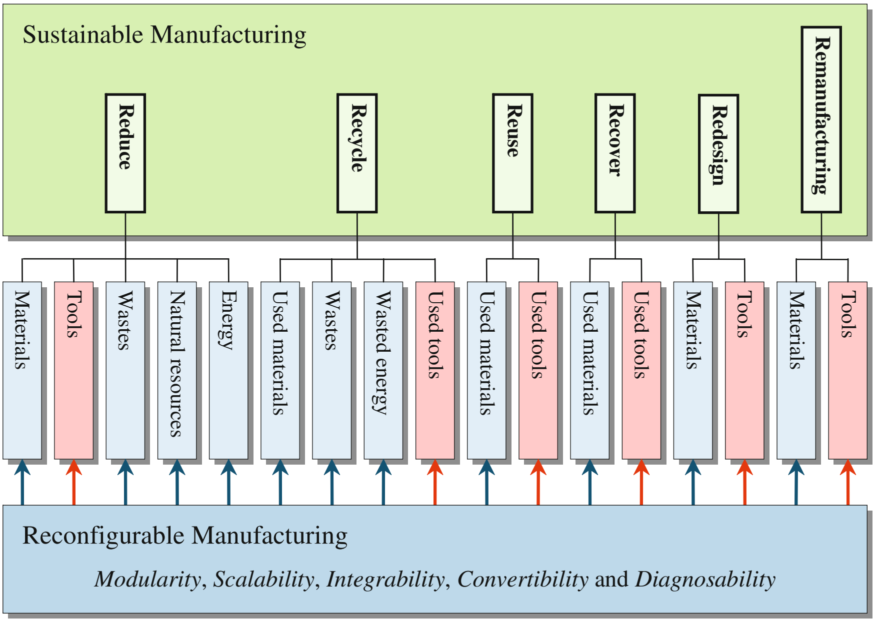

Fig. 5.9 From reconfigurable manufacturing to sustainable manufacturing

As shown in Fig. 5.9, in order to examine the contributions of an RMS to sustainability, the activities in a sustainable manufacturing are classified into 6R, i.e., *reduce*, *recycle*, *reuse*, *recover*, *redesign* and *remanufacturing*; these activities are applied to either *materials* or *tools*. Based on the above discussions on components and design criteria of an RMS system, the involved activities for the purposes of sustainability are highlighted in the figure. Currently, the focus of an RMS is on the reconfigurability and sustainability of machines and tools. There is a long way for the reconfigurable manufacturing paradigm to evolve to a sustainable manufacturing paradigm. Two main reasons are: (1) the reconfigurable manufacturing system is still an open system, which needs a clear definition of system boundaries, and the system paradigm is the result of a local optimization, and (2) the reconfiguration and optimization of manufacturing resources are focused, in particular, on machines and tools. Little effort has been made in planning and scheduling from the perspective of materials and wastes.

The system paradigms, such as an RMS that is based on a local optimization of manufacturing systems, make a limited contribution to sustainability and the value of a product in its lifecycle. The role of a manufacturing system in the value-added chain has to be re-examined. As far as the sustainability is concerned, the boundaries of manufacturing system in the product lifecycle cannot clearly be defined anymore; at least, the boundaries of a manufacturing system can be defined in different ways based on the perspectives of designers. Therefore, research directions towards the evolution of today’s manufacturing system paradigms to sustainable manufacturing need to be researched carefully. Cloud manufacturing is such an enabler.

5.4.2 Cloud Manufacturing Towards Better Sustainability

Recently, Cloud computing, e.g., Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS), has emerged as a new-generation service-oriented technology to support multiple companies to deploy and manage services for accessing and exploiting over the Internet. Based on Cloud computing, Cloud manufacturing (or Cloud computing for manufacturing) would provide a cost-effective, flexible and scalable solution to SMEs by sharing complex manufacturing software with lower support and maintenance costs. The development of Cloud manufacturing includes design of four layers [38]:

- *manufacturing resource layer*, such as manufacturing equipment, sensors, servers, etc.;
- *manufacturing virtual service layer*, in which manufacturing resources are identified, virtualized, and packaged as available services. Identification and communication technologies have been researched, including wireless sensor network, RFID, Internet of Things, MTConnect [39], etc.;
- *global service layer*, which relies on a suite of Cloud computing technologies such as PaaS to take global service computing and supporting for various demands and requirements; and
- *application layer*, which is the interface for users to invoke services for various applications.

As a new manufacturing paradigm and an enabler towards better sustainability, Cloud manufacturing is gaining attentions recently. Several research projects have been funded by the European 7th Framework Programme (FP7) to investigate important research issues and applications of Cloud manufacturing. For example, the project ManuCloud is to investigate and develop a Cloud-based infrastructure to provide better support for on-demand manufacturing supply chains in photo-voltaic, organic lighting and automotive sectors [40].

Cloud manufacturing can serve as the vehicle towards better sustainability via a modular approach. Wherever relevant, modules with sophisticated technologies for online tracking of resource utilization, multi-objective decision support for planning and simulation, and on-board manufacturing execution control can be activated by a common Cloud manufacturing platform to enhance responsiveness, adaptability, reliability, and optimality in achieving first-time-right processes. Thus, a portable solution at low cost can be offered to the pragmatic mind of SMEs without losing the depth where needed. As shown in Fig. 5.10, the common services platform supports the service modules of machine availability monitoring

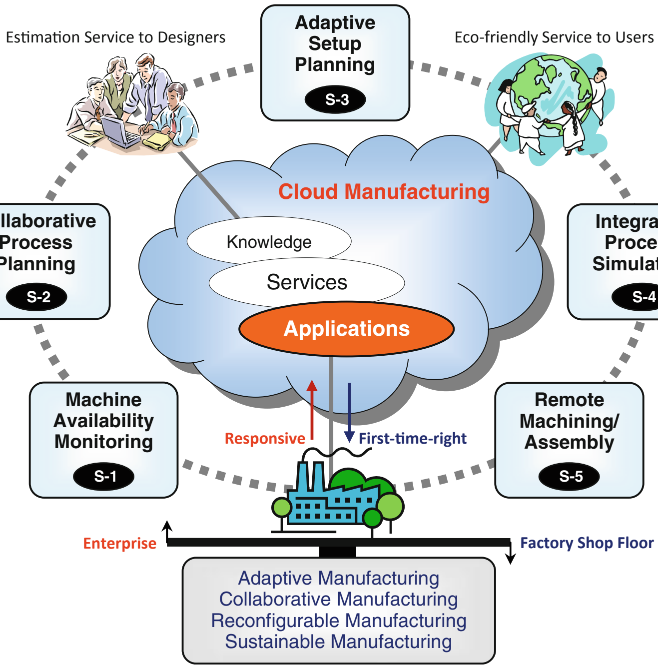

Fig. 5.10 A Cloud manufacturing platform for the future

(S-1), collaborative process planning (S-2), adaptive setup planning (S-3), and process simulation (S-4) are built into the platform. These technical modules, realized as *decision-support services*, are further tested and integrated with the common Cloud platform via web interfaces. S-2 and S-3 are essential manufacturing services in that they provide collaborative and adaptive solutions, having real-time access to the availability and utilization information of machines. In parallel to these, more technical modules are designed for better sustainability: (1) an estimation service to help designers at early product design stage to check manufacturability and sustainability, and (2) an eco-friendly service to help customers to reduce energy and resource consumption. This convergent engineering approach ensures that the application view of industrial users is converging with the development view of the system components (services). For this purpose, an iterative process of joint specification, design and feedback is possible between engineers and customers via the Cloud manufacturing platform.

Within the context, S-2, S-3 and S-4 can be regarded as a set of SaaS (Software as a Service), S-1 provides real-time information service, and S-5 enables MaaS (Machining as a Service) and AaaS (Assembly as a Service). In addition to cost, time and quality concerns, the issue of sustainability is taken into consideration during process planning and optimization.

5.5 Future Research Directions

Requirements of sustainability are ubiquitous. The major drivers of sustainability are customer demand patterns, governance and regulation, public values, environmental priorities, the shortage of natural resources, and increasing energy cost [35, 36, 41]. All entities involved in the lifecycle of a product should be optimized with the consideration of sustainability.

Existing paradigms have long been developed for the manufacturing phase of products; manufacturing systems are usually optimized based on the requirements of cost, quality, time, and product personalization. Unfortunately, no system paradigm exists to meet the requirements of sustainability seamlessly. The next-generation system paradigm is likely a hybrid of various paradigms such as lean production and reconfigurable manufacturing. However, there is unlikely a totally new sustainable manufacturing paradigm. In sustainable manufacturing, it is necessary to bridge manufacturing processes with sustainability in design and optimization, and some quantifiable models for waste and energy are essentials. It is the time for us to re-examine the limitations of existing system paradigms, and explore the means to evolve them into sustainable manufacturing.

While a clear view of a sustainable manufacturing system has yet be defined, the requirements of sustainability have been discussed extensively. Correspondence of an RMS to sustainability has been investigated, and the limitations of an RMS paradigm have been identified from the perspective of sustainability. As mentioned earlier, many researchers have worked on the improvement of system design to achieve better sustainability [30, 36]. The suggested aspects of future endeavors to further increase the sustainability of a manufacturing system are summarized as follows.

5.5.1 *Horizontal and Vertical System Integration*

As illustrated in Fig. 5.6, the scope of a sustainable manufacturing system must be expanded significantly in comparison with a traditional manufacturing system. To make a manufacturing system sustainable, extended efforts must be made at all levels from process, product, and system related to the entire product lifecycle. At the process level, one must improve technologies and process planning to reduce energy and resource consumptions, toxic wastes, and occupational hazards. At the product level, traditional *reduce*, *recycle*, *reuse* (3R) must be shifted to 6R including *recover*, *redesign*, *remanufacturing* [14, 25]. At the system level, all aspects including pre-manufacturing, manufacturing, use and post-use must be taken into consideration altogether [36]. To this end, traditional system architecture has to be expanded vertically and horizontally to cover more activities involved in the entire product lifecycle.

5.5.2 Modeling and Optimization of Energy and Wastes

Clearly, considerable amount of energy cost has been spent in manufacturing. The quantification of energy cost for different manufacturing process becomes a must. The efficiency of energy utilization in manufacturing is an important indicator of performance. Now, the focus of energy efficiency studies is changing from energy-efficient products to energy-efficient manufacturing [37]. Note that wastes from a sustainable manufacturing are very different from the wastes from lean production. Lean production seeks to eliminate traditional production objectives like cost or time while the green is concerned with wastes that impact the environment [41]. The example of studies towards this direction is the work by Heilala et al. [42]. They estimated energy use based on information provided by equipment manufacturers, which has led to the potential energy saving of 20–27 %.

5.5.3 Integrated Modeling and Simulation Tools

Modeling and simulation for manufacturing digital enterprise has a positive impact on design and optimization of manufacturing system. In order to maximize the sustainability, it is desirable to integrate environmentally conscious manufacturing efforts with design of manufacturing system. Note that most of the existing tools are for minimizing production cost and time to market, and the frequently used objective is profit optimization [43]. These tools have to be expanded to further include the consideration of sustainability. New simulation tools must be able to capture pre-life and end-of-life in a simultaneous manner, by closing the loop of pre-life, usage life, and end-of-life so as to enable sustainable, multi-life cycle product design and recovery [22]. The features of next-generation modeling and simulation tools are: (1) environmental impact calculations in combination with discrete event simulation, and (2) a virtual analysis for level-of-automation evaluation in combination with ergonomic considerations [42].

5.5.4 Green Manufacturing Processes

Croom et al. [17] investigated the relationship between innovative manufacturing techniques and environmentally sustainability, and concluded that the companies that rely on innovative and cost-effective production practices are often the leaders in sustainable manufacturing. Manufacturing processes of a product are essential. Manufacturing processes consume resources directly and produces environmental wastes and pollution, as well as being the main factor that affects sustainability. Efforts to minimize the negative environmental impacts of manufacturing processes can be classified into three categories: (1) process improvement and optimization,

(2) new processes development, and (3) eco-friendly process planning. Limited works have been published, which focus on the integration of environmental considerations with process planning [22, 44].

5.5.5 Towards Cloud Manufacturing

Cloud manufacturing is the promise of the future. This is true especially for SMEs. Building on top of the Internet- and Web-based services, it enables collaborative, adaptive, cost-effective, and sustainable manufacturing. The Wise-ShopFloor [45] and Web-DPP [46] are two examples of the previous attempts towards Cloud manufacturing. Future directions of Cloud manufacturing would include innovative and adaptive process planning services, knowledge-based and on-demand operation simulation services, resource utilization and availability monitoring services, setup planning and optimization services, dynamic and real-time scheduling services, and energy and resource estimation services. In a longer term, eco-friendly product design services and shop-level manufacturing services (machining, assembly, etc.) will also be made available. As a result, it supports SMEs to move from developing and maintaining resource-intensive and stand-alone software and hardware systems to a flexible and cost-effective service solution accessible and configurable over the Internet from anywhere at any time. However, when using Web or other Internet-based approaches, the secrecy of any proprietary information must be properly maintained and managed. In summary, service-oriented Cloud manufacturing is a clear path for future manufacturing companies.

5.6 Conclusions and Future Works

This chapter systematically reviews, analyses and compares different manufacturing system paradigms. The emphasis is given to manufacturing sustainability in relation to environment, society and economy. Among many system paradigms, the most promising ones such as reconfigurable manufacturing and sustainable manufacturing are analyzed in detail. It is also highlighted that Cloud manufacturing can implement and achieve a better sustainability in addition to the requirements on responsiveness, adaptability, cost-effectiveness, and distributed collaboration. It can also incorporate other advanced features, such as Just-In-Time, Plug-n-Play, self-reconfiguration and scalability, in realizing energy-efficient first-time-right decisions for manufacturing planning and control.

As illustrated in Fig. 5.1, manufacturing systems have been evolving over time to meet changing customers' requirements and emerging technologies. Given the limited natural and renewable resources today, sustainability is high on agendas of everyone. The 6R (reduce, recycle, reuse, recover, redesign, and remanufacturing) will be a common practice of manufacturing companies. Reducing energy/resource consumption becomes another important factor for multi-objective optimization.

The authors realized the needs and responsibilities in achieving a better and long-lasting sustainability, and will continuously work in the following areas.

- Process-oriented dynamics-based energy modeling for process planning and machine/robot control
- Situation-aware and energy-efficient process planning and setup planning
- Real-time resource and energy consumption monitoring
- Implementation of Cloud manufacturing services and testing

Finally, it is worth of mentioning that Cloud manufacturing is not a replacement of reconfigurable and sustainable manufacturing paradigms but instead a vehicle to realize a much better sustainability of future manufacturing activities in a distributed and dynamic environment. Sustainability cannot be achieved by a single company. It requires collective efforts of many participators, and therefore a new system paradigm of Cloud manufacturing can be applied to support such a collaboration.

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Chapter 6
Lifecycle Sustainable Information Management for Waste Electrical and Electronic Equipment

Weidong Li, K. Xia and L. Gao

Abstract Sustainability has become a critical driving force shaping the future of Waste Electrical and Electronic Equipment (WEEE) management. In this research, lifecycle information and flow management has been investigated to enable transition from the current "management authority-centric reporting model for WEEE" to a new "globally distributed and sustainable management model for WEEE". In order to achieve the target, case studies on LCD TV WEEE have been conducted to understand supply chain information flows and recovery and remanufacturing processes. Based on that, information/flow framework design for WEEE management has been explored.

6.1 Introduction

The global resource allocation and increased demand for welfare and new products have increased more production activities in recent years. However, the rapid economic development has been hindered by the increasing concerns of the scarcity of natural resources and environmental issues. Statistics show that from

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1985 the resource consumption on the global level has been higher than the ecological capability of the Earth. It is estimated that the required bio-capacity of two Earths is necessary to satisfy the need of the development in 2050 according to current trends [1]. On the other hand, more and more products after services are filled up in landfills. Among them, Electrical and Electronic Equipment (EEE) and their Waste Electrical and Electronic Equipment (WEEE) are becoming important and challenging waste streams in terms of quantity and toxicity.

With the populations of 1.33 billion in China and 0.5 billion in the EU, both regions are experiencing significant growth of WEEE per year. There is approximately 7 million ton of WEEE generated in the EU per year [2]. In China, 1.1 million ton of WEEE is generated per year, and China is the second in the world in the landfill and incineration of WEEE [3]. Due to rapid technical innovations and shorter usage lifecycle of electronic products, WEEE is growing much faster than any other municipal waste streams. In order for the Earth to be cleaner, sustainability has become a critical driving force shaping the future of WEEE lifecycle management patterns. An important research issue is to develop sustainable processes and information management technologies to better manage WEEE after service to generate less or even zero environmental impact and CO2 footprint.

It is envisaged that in future all WEEE need to be traceable, manageable, recyclable, recoverable and remanufacturable [4]. The WEEE Directive was enacted as the European law in 2003, and the EU Member States were required to transpose the provisions into national laws by August 2004. As one of the biggest EEE and component production nations in the world, China has realized the serious environmental issues from WEEE and addressed them as a rising priority. Many EEE/WEEE companies including manufacturers, suppliers, distributors, retailers, recyclers and remanufacturers geographically distributed in the EU and China have formed closer supply chain partnerships and networks. The operation patterns and practices of the Chinese WEEE management are influencing the entire chain in a deeper and wider scope. For instance, it is infeasible to implement sustainable WEEE management effectively in the EU if Chinese OEMs (Original Equipment Manufacturer) and suppliers [especially SMEs (Small and Mid-size Enterprises)] are incapable to incorporate the overarching eco-requirements imposed by the European legislation in their information management of WEEE.

A GREENet (Globally Recoverable Electrical and Electronic Equipment) research project has been recently funded by the European Commission Framework Program 7 (EU FP7) to support four European universities (Coventry University of UK, Royal Institute of Technology of Sweden, Strathclyde University of UK, and Technical University of Cluj-Napoca of Romania) and four Chinese universities/institute (Huazhong University of Science and Technology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Tsinghua University and Fudan University) as a consortium to investigate the global WEEE information management collectively. Research has being carried out to propose a global WEEE information management architecture, a RFID--based WEEE tracing service and a smart remanufacturing decision-making service. In this chapter, the progress of the project on research gap analysis, case studies on LCD TV WEEE and some designed information/flow frameworks are reported.

6.2 Gap Analysis on WEEE Information Management

The EU and China are presently facing a number of technical challenges in implementing and operating the EEE/WEEE management in global chains. According to the WEEE Directives, a producer's (manufacturer, brand owner or importer) responsibility is extended to the post-consumer stage for their EEE (i.e. WEEE), instead of stopping at selling and maintenance (i.e. Extended Producer Responsibility—EPR [5]). EPR is aimed at encouraging producers especially manufacturers to provide cradle-to-grave support to reduce environmental hazardousness, such that they work closely with remanufacturing industries to recover maximum values and reduce environmental toxicity/hazardousness. However, considering the current technical constraints especially in the global context, the operations of WEEE management (i.e. the producer compliance scheme) do not effectively achieve the aim of the WEEE Directives and EPR. The scenario is illustrated in Fig. 6.1. For instance, the three major sources of WEEE in China are households, offices and OEMs. Yang et al. report that there is no actual official data for WEEE generation and flow in China [6]. People seldom dispose of their used EEE in China even if they are out of date or broken due to a perception that the goods might be useful in the future or they might sell them [7]. The situation is illustrated in Fig. 6.2. The gap is summarized in Fig. 6.3.

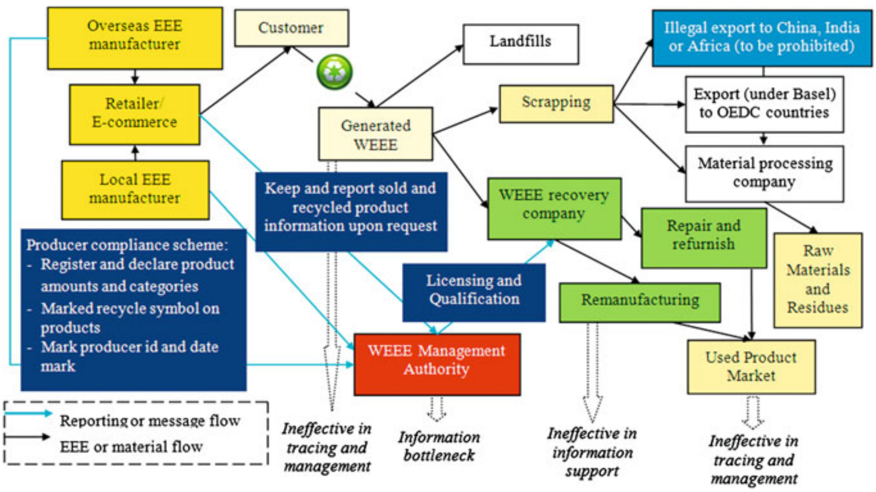

Fig. 6.1 The EEE reporting and WEEE recycling/recovering mechanism

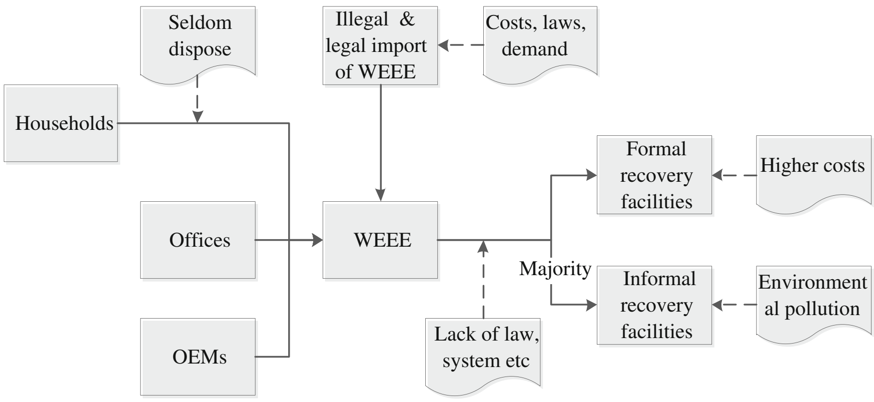

Fig. 6.2 The flow of the WEEE management in China

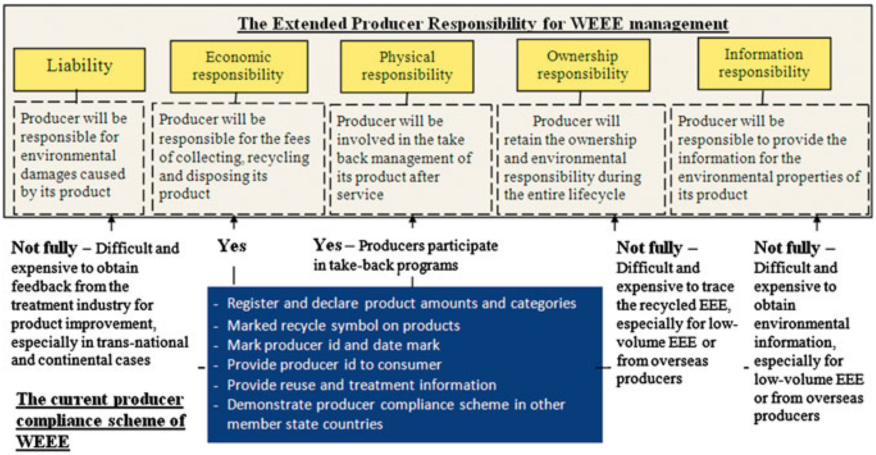

Fig. 6.3 Gaps between the EPR and producer compliance scheme

One of major reasons is the lack of information management services for WEEE in global EEE/WEEE chains. This is expanded below.

- According to the WEEE producer compliance scheme, producers are required to report to the WEEE management authorities for product quantity, recycling and remanufacturing information periodically. Owing to the active E-Commerce and more personalized EEE design, online transactions and mass-customized productions are more frequent. This brings challenges to record the dynamic, low-volume, and varied WEEE information. In the current operation of WEEE management, authorities will be the "information bottleneck" so that information exchange across the entire EEE/WEEE chains is inefficient or even impossible not only internationally, nationally but also regionally. Closer supply chain-spanning information linking between manufacturers, suppliers, distributors, retailers, recyclers and remanufacturers should take place. In the current situation, there is almost no any distributed information services deployed in the Internet to enable the convenient and secured retrieving of EEE/WEEE information. To tackle the issue, it is imperative to understand WEEE information flows so as to support the dynamic and robust information management in global EEE/WEEE chains.

- Producers need to report total weights for each category of products, to maintain records and make them available for the whole lifecycle until the recycling and remanufacturing stage and to mark new products with a producer identifier and a crossed out wheelie bin symbol. It requires that the last owners must be able to dispose of products free of charge and producers will pay all or a significant part of the free take-back from this date, setting increasing reuse, recycling and recovery targets. However, many enterprises are faced with difficulties in the traceability of their EEE and components to recycle and remanufacture. In order to identify the producer, EEE needs to be embedded with the producer's name and the date of introduction to the market. Information needs to be provided to enable recycling/remanufacturing facilities to identify EEE, the type and location of hazardous substances and eco-recovery plans efficiently. Due to process related constraints, it is laborious and inaccurate to position readers/writers (such as barcodes) directly to components for identification and life status information retrieval. To develop a WEEE information tracing service with reliable and efficient information identification functions is crucial to keep the continuous traceability and provide appropriate recycling and remanufacturing information of WEEE during lifecycle.
- Recovery/remanufacturing of WEEE, which has been viewed as a "hidden green giant" during WEEE management, is attracting increasing attentions of researchers and practitioners in recent years. Good recovery/remanufacturing flow management will be one of the stronger driving forces for industries to adopt in their practises to balance economic and environmental targets, and close gaps between shorter innovation cycles and longer lives of WEEE. On the other hand, recovery/remanufacturing legislative initiatives are underway in the EU and USA to ensure OEMs and suppliers to provide free access to remanufacturing information facilities in global chains. However, the end-of-life information flows of WEEE between manufacturers and recycling/remanufacturing enterprises have not been effectively established. To establish a better understanding on recovery/remanufacturing flows is therefore paramount for enterprises to apply sensible recovery/remanufacturing strategies to recover diverse WEEE.

In the GREENet project, a technical solution is proposed to change from the current "management authority-centric reporting model" to a new "globally sustainable management model for WEEE" with the following innovative features: a "generic" global WEEE distributed information service architecture, an "efficient" WEEE tracing service and a "smart" recovery/remanufacturing service

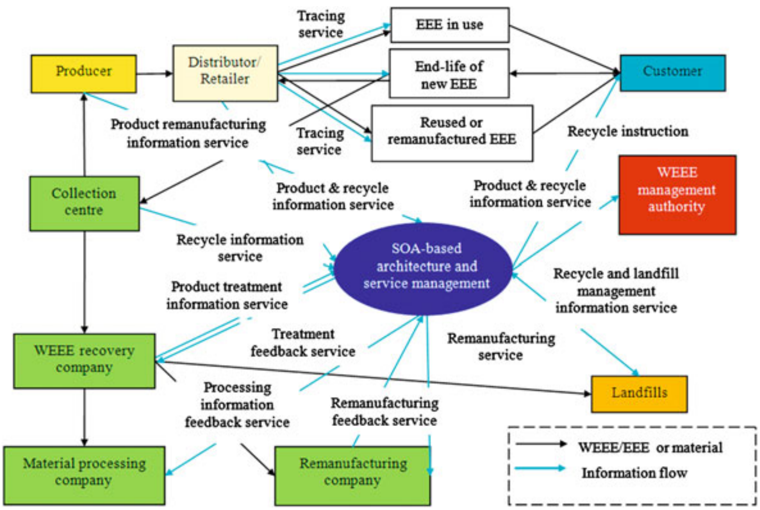

Fig. 6.4 Service oriented information framework

for variant WEEE. The new technology, which is shown in Fig. 6.4, has been based on the new generation.

Service-Oriented Architecture (SOA) to streamline bi-directional, dynamic, efficient and secured information flows across the entire global EEE/WEEE chains. This project will focus on the following information services:

- A SOA-based architecture that is able to facilitate the establishment of a generic and robust distributed information service framework to manage global EEE/WEEE information networks;
- A wireless tracing service supported by the latest RFID technology and integrated with the SOA-based architecture to enable EEE/WEEE enterprises to implement pro-active WEEE identification management so as to fulfill their eco-responsibilities;
- A smart remanufacturing service, which is based on the retrievable remanufacturing information in the SOA-based architecture, to use artificial intelligent optimization algorithms (i.e. modern bio-inspired optimization algorithms) for effective remanufacturing and recovery planning of WEEE.

For instance, with the support from the above frameworks, the process, information representation and service functions for the lifecycle management of a mobile phone WEEE to be supported by the proposed architecture and services are illustrated in Fig. 6.5. In order to build up the above architecture and smart services, case studies are important to obtain the better understanding of WEEE information and recovery/remanufacturing flows. The following describes a case study on LCD TV WEEE management and its recovery/remanufacturing information/flow frameworks.

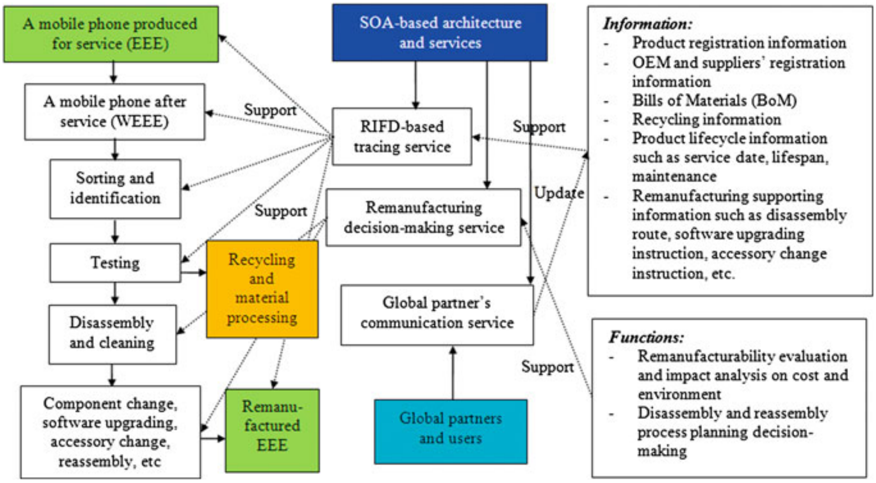

Fig. 6.5 A case to illustrate the process, information and functions of the system

6.3 Case Study and Information Framework Design

Changhong Plc is one of the major consumer electronics producers in China. TV produced in Changhong is classified into five groups: CRT TV, LCD TV, PDP TV, OLED TV and RP TV, and the LCD TV shares the biggest market of TV (the TV shares in the worldwide market is shown in Table 6.1). A LCD TV is typically assembled through three main parts: front cover assembly part, back cover assembly part and base assembly part. Among them, front cover assembly part is composed of surface frame, remote control receiver board, control button board, main board, power supply board, low-noise block converter (LNB) board, and DVD Rom (optional). The typical exploded view of a LCD TV is given in Fig. 6.6, which shows 32 main parts of the LCD TV. The part list is shown in Table 6.2.

6.3.1 LCD TV Supply Chain and Lifecycle Management

In the supply chain and lifecycle management of LCD TV and WEEE, there are several important players such as suppliers, OEMs, distributors, retailers,

Table 6.1 Worldwide market share of TV (from displaysearch.com)

Date	LCD TV	PDP TV	OLED TV	CRT TV	RP TV
Q2/2011	80.1 %	7.6 %	0.0 %	12.3 %	0.0 %

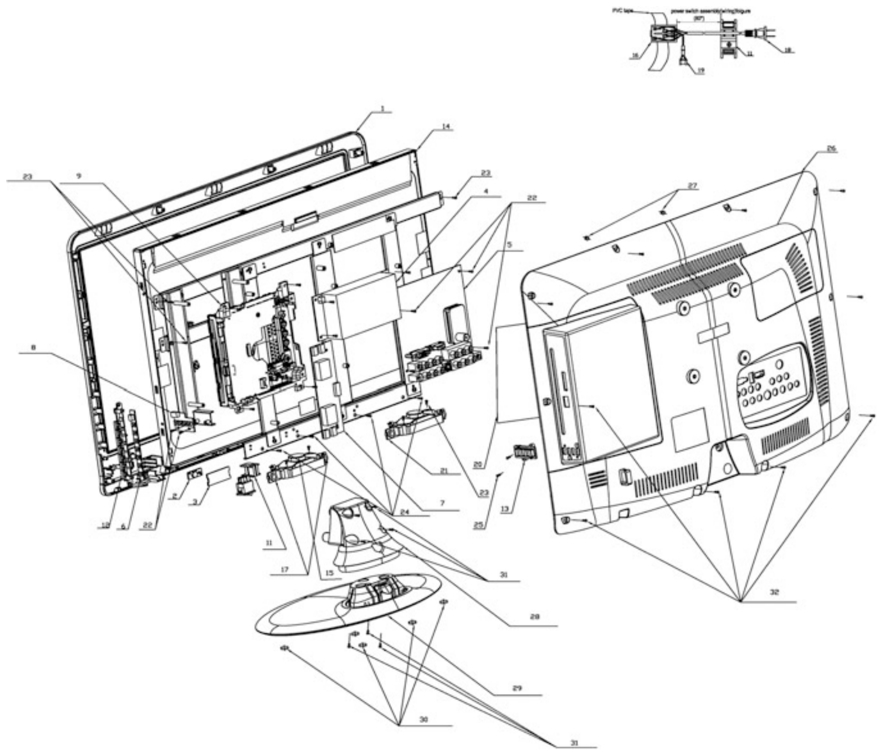

Fig. 6.6 The exploded view of a LCD TV

consumers, repair stations, collectors, second-hand sellers, recovery facility, etc. A flow of LCD TV/WEEE and the players are shown in Fig. 6.7. Suppliers provide materials and parts for OEMs. Recovery factories become suppliers when they produce recycled materials and reused parts for OEMs. Repair stations get new parts from suppliers and OEMs and reused parts from recovery factories. TV OEMs fabricate their self-made parts and assemble them with outsourced parts from suppliers. Self-made parts generally include surface frame, kinds of PCBs, back cover, brace, seat etc. Outsourced parts generally include LCD screen, DVD Rom, dynamoelectric loudspeaker, etc. Customers are categorized as business consumers and residential consumers from which the recovery system collects WEEE. The two primary modes of collection from business consumers are end of lease and asset recovery. Meanwhile, the two modes of collection from residential consumers are municipal pick-ups and retail take-back (such as buy-back, trade-back and free program). Customer returns is not only the return reasons for reverse logistics. The other reasons include manufacturing returns, distribution returns etc. Therefore, collectors take WEEE from OEMs, distributors, retailers, business consumers, residential consumers and second-hand sellers. Importing of obsolete

Table 6.2 List of main parts according to exploded view of LCD TV

No.	Name	Code	Amount
1	Surface frame	1-1-1	1
2	Lens	1-1-2	1
3	Remote control receiver board	1-2	1
4	Power supply board	1-5	1
5	Main board	1-4	1
6	Control button board	1-3	1
7	Inverter	1-1-3	1
8	Control button board for DVD/DVD	1-1-4	1
9	DVD rom	1-7	1
10	Metallic mounting plate	1-1-5	1
11	Wire clip	1-1-6	1
12	Button	1-1-7	1
13	Button for DVD/DVD	2-1	1
14	LCD screen	1-1-8	1
15	Dynamoelectric loudspeaker	1-1-9	2
16	Power switch	1-1-10	1
17	Rubber washer	1-1-11	4
18	Electrical wire	1-1-12	1
19	Connector plug	1-1-13	1
20	Insulation board	1-1-14	1
21	Pedestal for loudspeaker	1-1-15	2
22	Screw (M3×8)	1-1-16	16
23	Tapping screw (3×8BTHCH)	1-1-17	7
24	Tapping screw (4×8BTHCH)	1-1-18	4
25	Tapping screw (3×8KTHCH)	1-1-19	2
26	Back cover	2-2	1
27	Rivet nut	2-3	4
28	Brace	3-1	1
29	Seat	3-2	1
30	Rubber washer	3-3	5
31	Tapping screw (4×12BTHCH)	3-4	7
32	Tapping screw (3×10BTHCH)	2-4	10

TVs is not considered since it is not allowed by law. After being checked and sorted, parts of collected obsolete TVs are directly re-used and the others are sent to recovery facilities for process recovery.

6.3.2 Recovery and Remanufacturing Flows of LCD TV

The general recovery and remanufacturing processes as an inverted pyramid are shown in Fig. 6.8. Recovery and remanufacturing include the direct recovery and indirect recovery and remanufacturing. In addition, Recovery can include several

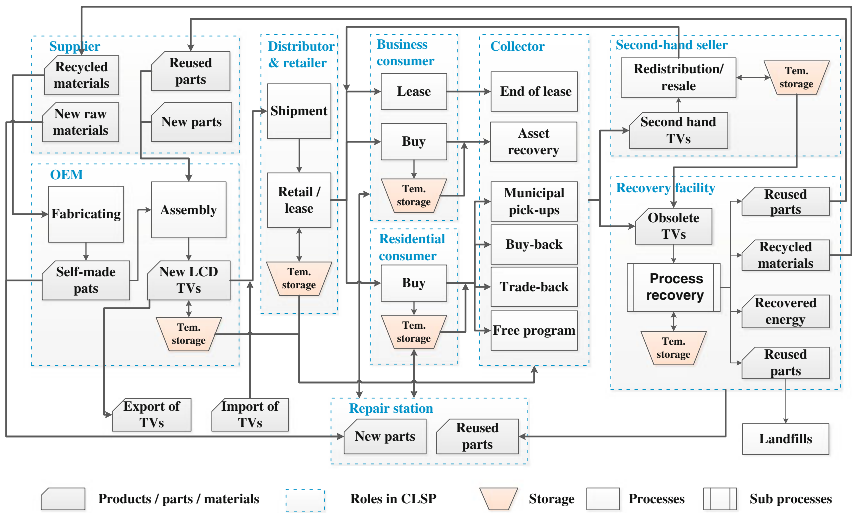

Fig. 6.7 Supply chain and lifecycle flows of LCD TV and WEEE

cases such as product recovery and remanufacturing, component recovery and remanufacturing, material recovery, energy recovery, etc. The impact on the environment of recovery and remanufacturing from top to bottom of the inverted pyramid is from min to max, while the value recovered is from max to min.

The recovery and remanufacturing processes of LCD TV WEEE are shown in Fig. 6.9, including cleaning, product disassembly, checking and sorting, parts disassembly, material recycling, and energy recovery.

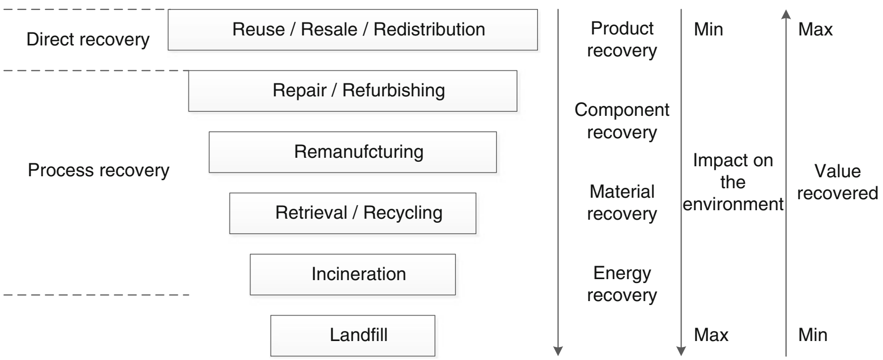

Fig. 6.8 Recovery and remanufacturing processes

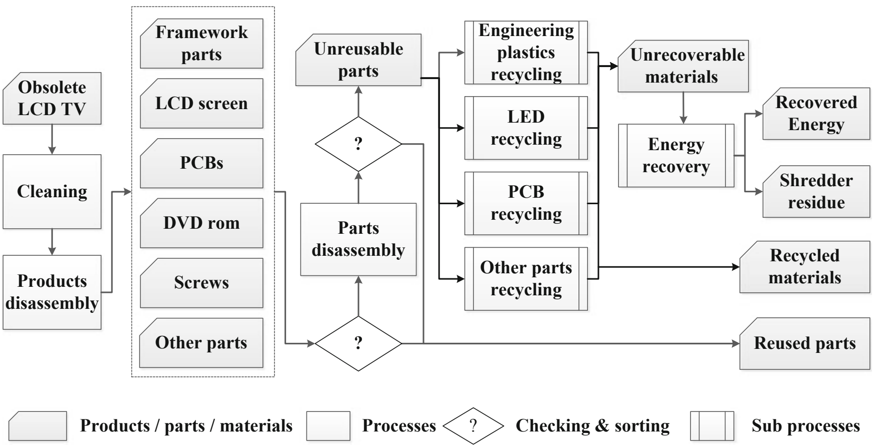

Fig. 6.9 Recovery and remanufacturing of LCD TV WEEE

After cleaned, obsolete TVs are dissembled to six main parts: framework parts, LCD screen, PCBs, DVD Rom, screws and other parts. Take the LCD TV as an example. The framework parts include surface frame, metallic mounting plate, insulation board, pedestal for loudspeaker, back cover, brace, seat and rubber washer. PCBs include remote control receiver board, control button board, main board, power supply board and control button board for DVD.

The disassembled parts then go through the processes of checking and sorting. If the parts are reusable and inspected to be good, it could be reused, such as DVD Rom, power supply board, insulation board, dynamoelectric loudspeaker and screws. Good LCD screens without obvious nicks may be also reusable. The next process is parts disassembly. Then there are more parts reusable, including lens, magnet (from loudspeaker), electronic components (or chips) and more crews. The others are considered as unreusable parts, which are the majority. They fall into four groups: framework parts, LCD screens, PCBs and other parts. Because the product life of TV is much longer than the design life of it, framework parts or PCBs would be out of date and undesirable to customers. The performance of used LCD screens also would not equal to that of new ones. There are many techniques to recycle materials from unreusable parts. Materials recycled from framework parts include recycled ABS and HIPS. The suitable plasticizer could be used to improve the toughness of recycled ABS or HIPS (form back cover). Taking a TV of type of LT24GX699EB from Changhong as an example, the net weight of the products is 5.4 kg, while the weight of materials of ABS and HIPS is respectively 549.5 and 739 g. That's to say ABS and HIPS hold 23.86 % of the product in weight.

The waste PCBs is a kind of important recoverable resource of nonferrous metals. Recoverable materials from PCBs include plastics, copper (Cu), iron (Fe), lead (Pb), tin (Sn), antimony (Sb), silver (Ag), nickel (Ni), aurums (Au), palladium (Pd) and platinum (Pt). Three kinds of techniques of reclamation and recovery are used to recycle waste PCBs, such as hydrometallurgical treatment, pyrometallurgical treatment and physically mechanical treatment.

There are three valuable and recoverable/remanufacturable parts in a waste LCD screen: panel glass, liquid crystal and indium tin oxide. Panel glass is special silicon glass without boron and alkali, so it is unable to be recycled by fusion as usual glass. After separated and crushed up, the panel glass used as one of the raw materials of red bricks or glazed tiles. Liquid crystal is expensive chemicals, and indium is also expensive. However, the technology of recycling LCD screen is not proven and in practice. There are demands and challenges in developing the techniques of recycling and remanufacturing LCD screens. In Chap. 2, a disassembly planning service has been reported.

6.3.3 Information Management for LCD TV WEEE

Before a WEEE is recovered and remanufactured, information about the product is needed. Information for recovery and remanufacturing is divided into 8 categories: factory information, tracing information, technological information for recovery and remanufacturing, feedback information, recovery/remanufacturing-oriented design support information, legal information, economical information and ecological information. Table 6.3 details the relevant information.

Factory information is thought to be the most important information for recovery and remanufacturing of WEEE. Identification of product helps to identify the WEEE. The physical characteristics of WEEE can be analyzed, such as magnetic, density and electric conductivity properties. Finally, the treatment strategy is decided, e.g. the strategies of disassembly include non-destructive and destructive disassembly. Information about joining is also helpful to disassembly. The conceptual data model of the factory information is shown in Fig. 6.10. The entities of manufacturer and supplier are inherited from entity of role-in-SC. Every role-in-CS has his unique role-ID, and so do entities of material and product. The entity of MBON is denoted in a tree structure, in which a note represents a component or part. Corresponding to every note, the materials bill, process sequences and joining can be found. Accordingly, EEE/WEEE information for tracing is shown in Fig. 6.11.

In the GREENet project, the information framework design from the LCD TV WEEE will be further developed and generalized to other WEEE management. Meanwhile, smart remanufacturing decision-making service has been partially developed (see Chap. 2).

Table 6.3 LCD TV WEEE information

Factory information	Identification of product	Product category
		Product code
		Product description
	BOM	Component number
		Material bill
		Process sequence
	Substances	Used substances
		Hazardous substances
	Joining	Joining mode
		Joining element
		Joining comment
Tracing Information	Utilization history	Consumer
		Serving time
		Maintenance history
		Reuse times
	Deterioration	Deterioration category
		Deterioration description
	Component's condition	Performance parameter
		Condition assessment
Technological information for recovery	Information for reuse	Product reuse
		Component reuse
	Technological information for disassembly	WEEE analysis
		Assembly analysis
		Disassembly strategy
		Disassembly process planning
		Required device
		Required tool
	Technological information for remanufacturing	Component analysis
		Remanufacturing strategy
		Remanufacturing process planning
		Required device
		Required tool
	Technological information for recycling	Material and substance analysis
		Recycling strategy
		Recycling process planning
		Required devices
		Required tool
	Technological information for energy recovery	Material and substance analysis
		Energy recovery strategy
		Energy recovery process planning
		Required device
		Required tool
Feedback Information	Product/component reuse feedback	
	Disassembly feedback	
	Remanufacturing feedback	
	Recycling feedback	
	Energy recovery feedback	
Recovery/remanufacturing-oriented design support information	Product structure design support	
	Process planning support	
	Materials choosing support	
	Joining design support	

(continued)

Table 6.3 (continued)

Legal information	2002/96/EC (WEEE Directive)
	2002/95/EC (RoHS Directive)
	China WEEE
	China RoHS
Economical information	New material price
	New component price
	New product price
	Recycled material price
	Reused component price
	Second-hand product price
	Collecting cost
	Treatment cost
Ecological information	Treatment energy consumption
	Treatment environmental pollution

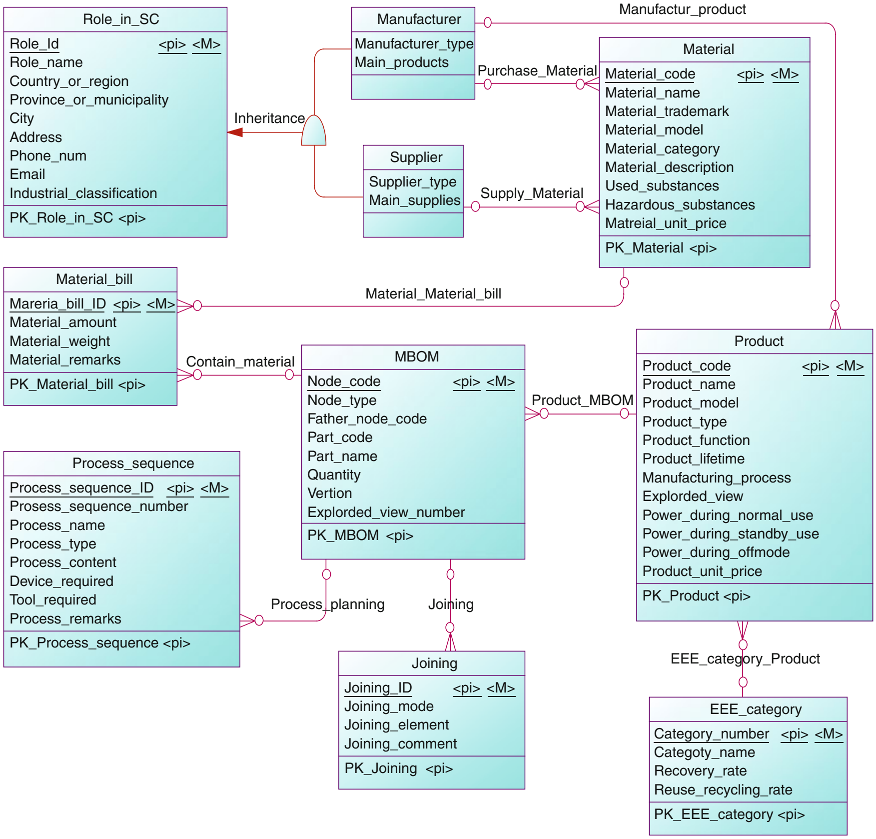

Fig. 6.10 Conceptual information model of factory information

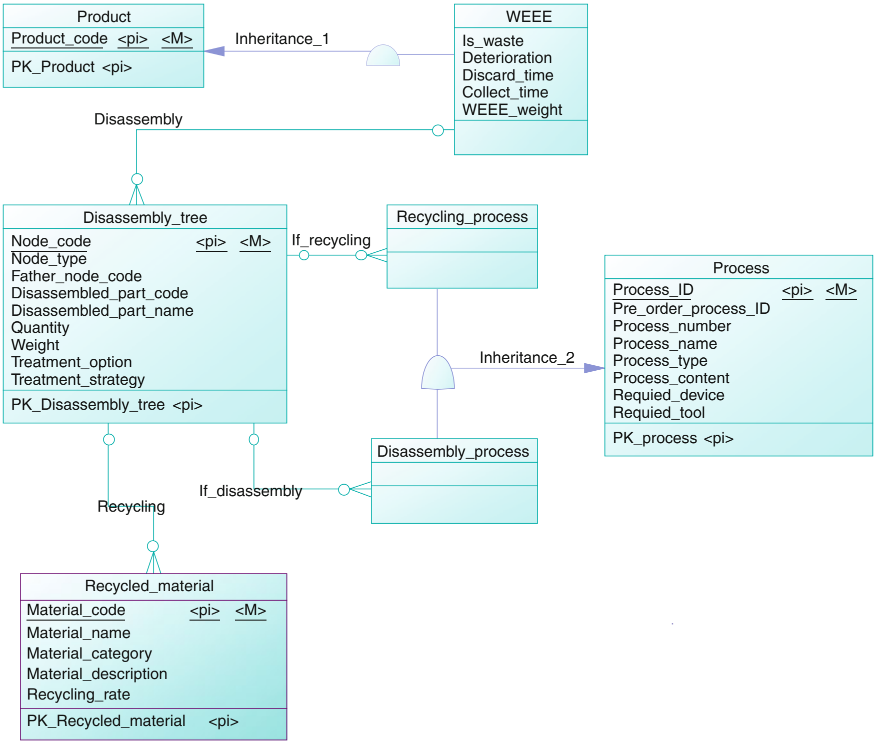

Fig. 6.11 Conceptual information model for recovery and remanufacturing

6.4 Conclusions

In this research, investigation and case studies on LCD TV WEEEE have been made to support sustainable WEEE management. With the innovative features including a generic global EEE/WEEE distributed information service architecture and smart EEE/WEEE services, the research outcomes will be a promising solution to change the current EEE/WEEE management from the traditional "management authority-centric reporting model" to a new "sustainable management model for WEEE". Detailed technical implementation of the research is under development, and more case studies are expected to verify and validate the research.

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Chapter 7
A Streaming Technology of 3D Design and Manufacturing Visualization Information Sharing for Cloud-Based Collaborative Systems

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Abstract One of the challenging problems that hinder the development of Cloud-based collaborative systems is the contradiction of large design or manufacturing visualization data and the limited bandwidth of the Internet and Web to share the data remotely to support collaborative work. Faster visualization of design and manufacturing models during collaboration has been needed for a long time. Recently, a new scheme for visualization has been presented, viz., the 3D streaming technology. 3D streaming technique can allow effective dispatch and access of large-volume design and manufacturing data as a series of patched streams across the Internet, and therefore provide a promising solution to overcome the obstacle. The key technology to realize the streaming technique is geometric simplification (or decimation) of 3D models. In this chapter, a new streaming technology based on a geometric simplification algorithm has been developed, in which two criteria are the crucial elements to control the collapse process for edges in 3D visualization models represented in VRML. After the simplification and sharing of a model, a developed refinement algorithm is carried out to restore the model from its simplified version back to its original, through combining the simplified model with some reconstruction data generated during the simplification process, therefore, to realize the streaming information sharing. The major feature of the streaming algorithm is that it has incorporated some advantages of the previously developed vertex decimation approach and edge collapse approach. Meanwhile, the mechanism of adaptive threshold parameters adopted in this work enhances the adaptability of the algorithm for various

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applications. Case studies and comparisons with some related works have been carried out to demonstrate the performance and potentials of the algorithm in terms of efficiency, adaptability and robustness.

7.1 Introduction

For developing a complex product, there is always a need for collaboration among the management and the functional departments such as design, marketing, finance, procurement, etc. Global manufacturing makes it difficult to frequently gather all the people in a meeting room to discuss and interact because of physical distance. Future product design and manufacturing systems are moving towards supporting Cloud-based collaborative activities, in which the geographically dispersed people, systems and resources can be integrated in an Internet environment and a Cloud enabled distributed design team across the traditional boundaries of physical and time zones can be set up [1–3]. One of the fundamental difficulties in implementing the Cloud-based distributed systems is to share design and manufacturing visualization models efficiently since the relevant data are usually huge in size and require unbearable downloading time over the Internet. In order to address this problem, 3D streaming has emerged recently to provide a data transmission technique to enhance the distributed collaborative product development. Streaming is defined as listening or viewing media in real time as it comes across the Internet, such as conventional streaming of video and audio. It does not require the user to download the entire file before he can see the data, thus a portion of the data can be seen while downloading is still in process. Through the 3D streaming technology, users can view and manipulate the portion of the model they need. Streaming technology is especially vital to the distributed CAD system, enabling faster transmission and visualization of 3D models in real-time. Taking an automobile as an example, a full model CAD file can be a few hundred or thousand megabytes. It seems impossible to view the entire model over the Internet. Moreover, not all components or details of the automobile may be required for viewing at each instant. Different groups of people may view only certain portion of the model for their purpose. With streaming technology, there is no need for the client to download the entire model and only a portion of the model needs to be viewed at one time. Hence, the body of the automobile can be streamed first, gradually increasing the level of detail or visual quality, while hidden components need not be streamed over. When specific parts of the automobile such as the engine need to be viewed, additional information will then be streamed over. This greatly facilitates the navigation of the model over slow network connection such as a dial-up modem. Figure 7.1 illustrates a consecutive streaming transmission process of a complex visualization model.

Conceptually, it requires at least two steps to implement 3D streaming over the Internet: simplification and refinement. Simplification is the concept of removing

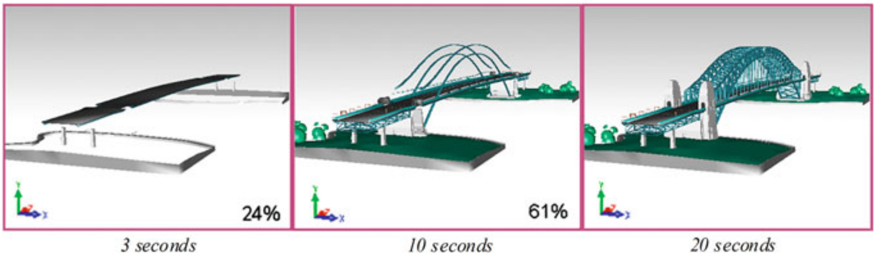


Fig. 7.1 3D streaming transmission processes of a model for remote visualization

as many polygons as possible from the mesh model in order to lower the storage requirements for rendering in the computer. Whereas, refinement provides functions to gradually retrieve the simplified model back to its original. To implement 3D streaming in a client/server architecture, the server is supposed to provide the functions of mesh simplification and refinement as well as communication with the clients. The clients should be able to send a streaming request, continuously receive the data and dynamically display the mesh through the viewer.

The term of the streaming technology is not new in video and audio. The technology was initially developed and applied for video and audio works to provide an effective and continuous way for transferring images and sound information, which are usually large in volume, over the Internet and Web. Through an incremental process, huge video and audio files can be downloaded from a server and further reach clients for gradual display. Similarly, in order to transmit 3D design or manufacturing visualization information across networks with the current (and even future) bandwidth and to enhance the visualization performance, the 3D streaming technology can be used to dispatch visualization information from a simplified level to a complex level in a gradual means. Most of 3D models are represented in boundary representation models. These boundary models are often discretized into triangular meshes for visualization, and through this way the problem of compatibility can be overcome by some general triangular mesh formats for being viewed over the Internet and Web. Among them, the Virtual Reality Modeling Language (VRML) has been widely used as a standard file format for representing 3D triangular mesh models across the Internet and Web. Different from video and audio which data structures are more natural to be rearranged as frames for streaming, VRML models are difficult to be decoupled as continuous streams and a set of geometric algorithms need to be developed to realize the streaming process.

Nowadays, one of the significant evolvement trends for commercial Cloud-based distributed systems is towards information streaming sharing to replace the traditional downloading technique. It is imperative to disclose the key algorithms behind the streaming technique of these systems. In this chapter, a new geometric simplification (or decimation) algorithm, which is crucial for establishing the streaming technique, will be investigated. The simplification algorithm can reduce an original VRML model to a smaller-size model and shorten clients' waiting time to obtain the first sight of the model across the network with a limited bandwidth capability. A follow-up refinement process, which is a reverse process of the simplification, provides clients with a gradually refined model through a smooth transition from the coarser model to the original one. Hence, the 3D streaming is actually the incremental simplification and refinement process through progressive transmission over the Internet. Figure 7.2 shows the visual effects of a VRML model with the different details through the process of simplification and refinement Table 7.1.

In this chapter, a new and extensible algorithm of geometric simplification for streaming VRML-based visualization models to support Cloud enabled collaborative design and manufacturing has been developed. This algorithm follows the principle of one of the previously developed simplification approaches, i.e., the edge collapse approach [7–11], to facilitate the decimation process of the models, while some characteristics of another approach, i.e., the vertex decimation approach [4–6, 16–19], has been enhanced and incorporated to improve the performance of the algorithm. Important elements of the algorithm include: (1) two criteria to control the collapse process for edges in the 3D models to diminish the amount of information, and (2) the mechanism of adaptive threshold parameters to enhance the adaptability of the algorithm and to meet the required decimation percentage through the adaptive threshold parameters. After the simplification and transmission of a model, a refinement process is used to restore the model from its simplified version back to its original, by combining the simplified model with reconstruction data generated during the simplification process, therefore, to realize the streaming information sharing. Through benchmarking comparisons with some related work, the potentials of the algorithm in efficiency, adaptability and robustness can be indicated clearly.

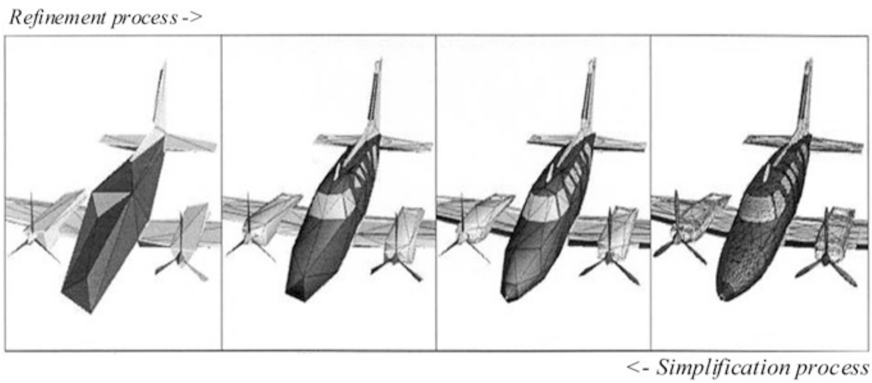


Fig. 7.2 Visual effects of the simplification and refinement processes

Table 7.1 Internet-based collaborative systems

Products	Characteristics and functions	Data sharing
Cimmetry systems autovue™	(1) A viewer for part and assembly models. (2) View, mark-up, measure, explode, cross-section, etc.	3D streaming
Conceptworks™	(1) An add-on viewer to solidworks. (2) View and mark-up.	3D streaming
Actify spinfire™	(1) A viewer for part models. (2) View, cross-section, measure, grid and ruler.	Download
Solidworks edrawing™	(1) A viewer for native or simplified solidworks files. (2) View, mark-up, measure, 3D pointer, animation.	Download
Centric software pivotal studio™	(1) A base platform to provide a workspace manager, a project organiser and a viewer for part models. (2) View, mark-up, video/audio conferencing, chat.	Download/3D streaming
Hoops streaming toolkit™	(1) A toolkit to provide 3D streaming APIs. (2) BaseStream class library, advanced compression, attribute (color, texture) support, object prioritization, etc.	3D steaming
Realitywave conceptstation™	(1) A VizStream platform, which consists a server and a client. (2) View, mark-up, message.	3D streaming
Autodesk streamline™	(1) A platform based on the VizStream. (2) View, measure, bill of materials.	3D streaming

7.2 Related Works

Simplification algorithms are the core of the streaming technologies. The algorithms are used to decouple a 3D visualization model as a series of simplified models while keeping some shape features to achieve acceptable approximations to the original shape. The fundamental principle underlying most of the developed research works is to iteratively select and eliminate geometrical components in visualization meshes, such as vertices and edges, according to some geometric optimality criteria (or heuristic rules). The developed algorithms can be generally categorized into three approaches [23–25]: (1) vertex decimation; (2) edge collapse; and (3) spatial clustering. A short summary of the previous work is given in Table 7.2, and the detailed discussions are below.

Table 7.2 A short survey of the related works

Works	Vertex decimation	Edge collapse	Spatial clustering	Major characteristics
Schroeder et al. [4]	O			The first and fundamental method for vertex decimation
				There are three consecutive steps: (i) vertex classification, (ii) vertex selection for removal, and (iii) retriangulation of the resulting holes after vertex removal
Renze/Oliver [16]	O			The retriangulation process is improved
Franc [5]	O			A hash function is used to bucket the vertices to be removed, and the efficiency of the vertex decimation process is improved
				Able to be applied to no-manifold models
Hamann [17]	O			A local curvature mechanism is used to measure the flatness of a region for deciding which triangles and vertices to remove
				The visualization effect of simplified models is improved
Qiu et al. [19]	O			A visibility culling method is used to optimize the visualization effect of simplified models
Garland/Heckbert [7]		O		Surface error approximation metrics are used to measure the quality of simplified models
Garland/Herbert [9]		O		Material properties are included, such as colors, textures, and surface norma.
Hoppe et al. [10]		O		An energy function is used to measure and control the quality of each reduced mesh
Hoppe [11]		O		A LOD structure is used to record a model to be simplified with different levels of details, and to create a streaming visualization effect
Rossignac/Borrel [20]			O	A bounding box is placed around the model to be simplified, and the bounding box is divided into a grid
				All the vertices inside a certain cell will be treated as one vertex so to simplify the object cell by cell
Low/Tan [21]			O	An adaptive vertex clustering technique is used to rank the vertices of a model by importance
Brodsky/Watson [22]			O	A spatial decomposition is built to determine splitting cells using the curvature of a model for simplification

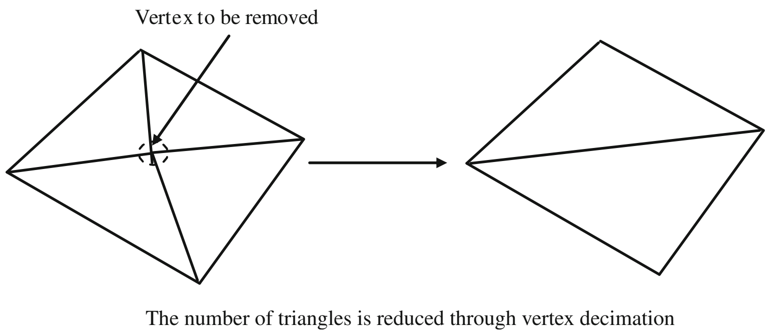


Fig. 7.3 An example of a vertex decimation process

7.2.1 Vertex Decimation Methods

Vertex decimation was initially proposed by Schroeder et al. [4]. This method can actually be divided into three steps: (1) vertex classification; (2) vertex selection for removal; and (3) re-triangulation of the resulting hole after removal. In the phase of vertex classification, it characterizes the local geometry of vertices as simple, complex, boundary, interior edge, and corner, among which only vertices of simple and interior edge types are possible candidates for removal. The step of vertex selection is performed by evaluating the decimation criteria to iteratively find the vertex with the smallest value of d, which is defined as the distance from the vertex to the best-fit average plane for the vertex's neighboring vertices. The last step is the triangulation of the resulting hole after the vertex removal. The approach is used to reduce numbers of meshes through removing vertices according to certain criteria and retriangulating of the meshes (Fig. 7.3 illustrate a simple example). Some algorithms have been developed following this decimation idea [5, 6, 16–19] but providing reasonable improvement in terms of efficiency and quality. Renze and Oliver [16] use the same criteria with that of Schroeder's method to decimate vertices, while the retriangulation process is improved. Franc [5] discussed the advantages and disadvantages of the vertex decimation algorithms compared with another major approach-edge collapse. A hash function is

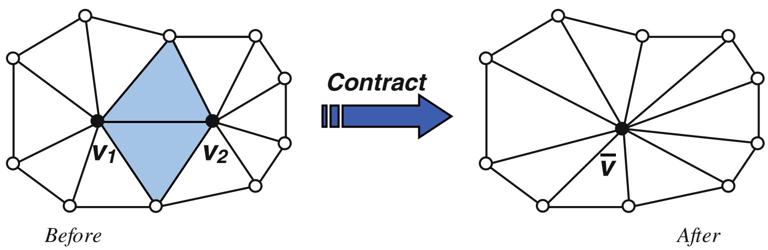


Fig. 7.4 An example to illustrate the edge collapse approach

used to bucket the vertices with removal criteria satisfaction into clusters, and the vertices are removed cluster by cluster from the least to the most important cluster after a sorting process. Therefore, the efficiency of the decimation algorithm can be improved. Moreover, it lifts the restriction of Schroeder's algorithm [4] to decimate non-manifold meshes. Hamann [17] developed a local curvature mechanism to measure the flatness of a region for deciding which triangles and vertices to remove. A triangle is removable if the sum of the curvatures at its vertices is low. In order to improve the computation speed, Cohen et al. [18] use geometric envelops built around an original model to constrain the selection of vertices that may be removed. Qiu et al. [19] developed a new criterion to select the removal vertices based on visibility culling to optimize the visualization effect of simplified models.

7.2.2 Edge Collapse Methods

Edge collapse is another promising simplification approach that preserves local topological and geometric properties better than the vertex decimation approach. Some of the common steps in some edge collapse-based algorithms consist of selection of vertex pairs (either edge or non-edge type) for collapse, and determination of the placement of a new vertex and the reconstruction of the meshes. In the selection of vertex pairs, a selection criterion is usually employed to choose the proper pair of vertices for collapse. Generally, it is ideal to iteratively collapse the vertex pair that least influences the overall shape after contraction. In the determination of the placement of a new vertex and reconstruction of the meshes, the vertex pair to be collapsed is combined and relocated as a single vertex, and all the neighboring vertices connected to the chosen vertex pair for collapse should be reconstructed to connect the target vertex. Figure 7.4 illustrates the process of the edge collapse approach.

Garland and Heckbert [7] introduced a surface simplification algorithm based on the edge collapse approach. The characteristics of this algorithm include high efficiency (rapid simplification process), good quality (high fidelity to the original model) and high generality (contracting both connected and unconnected pair of vertices). The algorithm chooses qualified vertex pairs and maintains surface error approximation based on the similar quadric metrics presented by Ronfard and Rossignac [8].

The error approximation function provides a more systematic way to evaluate the difference between a simplified model and its original model to optimally approximate the original representation. One major characteristics of the work is that it selects the arbitrary vertex pair to collapse if their quadric error is qualified, no matter whether the vertex pair is connected or not before collapse. Therefore, it can facilitate much better approximations, both visually and with respect to geometric error. Nevertheless, the limitation is that it is based on the assumption that topology is less important than the overall appearance. Garland and Herbert [9] further improved this algorithm to produce high quality approximations of complex polygonal surface models with material properties such as colors, textures, and surface normal. A natural extension of their original quadric error is presented to account for a wide range of vertex attributes. Hoppe et al. [10] presented a new edge collapse method to reconstruct a mesh surface with a smaller number of vertices than an original model while minimizing the deviation from the original topology. The method optimizes mesh representation by minimizing a so-called energy function, which is used to measure the quality of each reduced mesh. This method can reduce the number of faces in a dense mesh while minimizing the perturbation of the original shape. An enhanced work by Hoppe [11] is progressive meshes, providing a Level-Of-Details (LOD) structure based on the edge collapse approach. The basic idea of LOD is to represent a complex object as several objects with different geometric and topological details, and to refine the visualization effect from a coarse object to a detailed object. In other words, through simplifying the initial mesh representation of $\frown{M}$ into {Mn = $\frown{M}$, Mn−1, …, M1, M0} along the coarser direction, this LOD structure is able to render smooth visual transition along the sequence of $M_0 \rightarrow M_1 \rightarrow \cdots \rightarrow M_{n-1} \rightarrow M_n = \frown{M}$, which shows different levels of details of the original mesh model at different time.

7.2.3 Spatial Clustering Methods

Spatial clustering is another simplification approach significantly different from the former two. It was first introduced by Rossignac and Borrel [20] to process arbitrary polygonal input of mesh representation. Regardless of the original shape, it places a bounding box around an original model and divides the bounding box into a grid. All the vertices inside a certain cell will be treated as one vertex so that the original mesh model will be simplified cell by cell. The above method can be implemented very fast but usually alters the model's topology dramatically. Moreover, the quality of simplification is difficult to control since it depends on the size and number of grid cells, which cannot ensure a good approximation with topological loyalty. Low and Tan [21] developed a floating cell method to address this problem through providing an adaptive vertex clustering technique. In their method, vertices of a model are ranked by importance. A cell with a user-specified size is centered on the most important vertex and all vertices falling within that cell are merged. The R-Simp algorithm proposed by Brodsky and Watson [22] is another adaptive vertex clustering technique. In the algorithm, a spatial decomposition is built to determine splitting cells using the curvature of a model for simplification. However, these methods can only alleviate the problem of topological changes, while the vertex decimation and edge collapse are still the primary approaches in case that the major features and topologies of the original models need to be kept.

7.3 Simplification and Refinement of Visualization Models

7.3.1 Framework of the Simplification Process

A simplification framework for visualization models, which is illustrated in Fig. 7.5, has been developed to reduce the number of triangular meshes in 3D VRML models. In the framework, an improved edge collapse method has been proposed, in which two criteria are the crucial elements to control the collapse process for edges in meshes. Comparing to some previously developed vertex decimation methods and the edge collapse methods, this improved edge collapse method has the following advantages:

1. The characteristics of two approaches, i.e., the vertex decimation and the edge collapse, are incorporated. For instance, the vertex classification proposed in the vertex decimation approach is used here to provide an easier way to select the vertex pairs for collapse. Meanwhile, the step of the relocation of the new

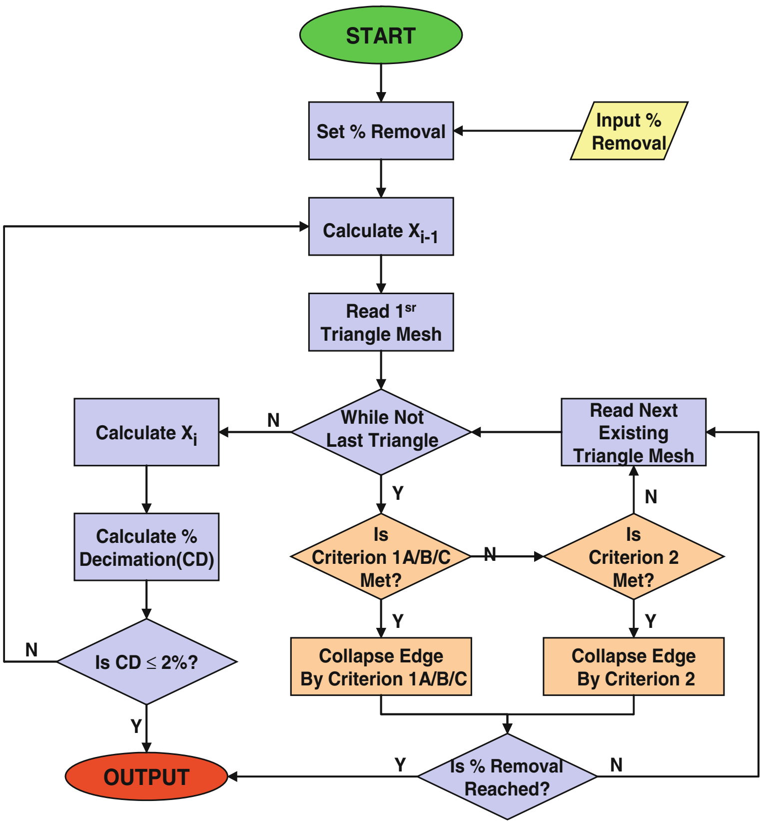


Fig. 7.5 The simplification framework of visualization models

vertex is simplified, and no extra calculation is required to determine the new position of vertices of a model after collapsing an edge from a triangular mesh and update the neighboring meshes;
2. It would also be more convenient for visualization during debugging since the collapse can be easily identified. Meanwhile, it would be easy to implement the follow-up refinement algorithm to restore the model to its original status after the transmission of the model via the Internet.

In the framework, the simplification algorithm will stop either after a prescribed amount of decimation (to within a certain limiting percentage), which can be predefined by a user, or until no further decimation can be achieved according to the criteria. Criterion 1 takes the precedence over Criterion 2 series and both criteria are subdivided into sub-criteria to handle different conditions.

For the criteria employed here, it is important to know the type of vertices in meshes and choose the proper pair of vertices for collapse. This is because not every vertex can be decimated or else it would cause the decimated model to be deformed or imperfect visually. Meanwhile, the execution of the various criteria depends on the values of the threshold parameters, and the algorithm needs to include adaptive threshold parameters. In the following Sects. 7.3.2–7.3.4, the classification of vertices is first defined. Criteria 1 and 2 and their sub-criteria are then explained. Finally, the discussion for the mechanism of adaptive threshold parameters is given. In Sect. 7.3.5, a refinement method, which is the reverse process of the simplification used to restore the model from its simplified version back to its original after the model transmission to realize the streaming process, is explained.

7.3.2 Classification of Vertices

According to Schroeder et al. [4], each vertex may be assigned to one of the five possible configurations: simple, complex, boundary, interior edge, or corner vertex (illustrated in Fig. 7.6). Interior edges, which are the boundary edges of a model, are the important elements to distinguish the types of vertices. In a VRML model, the relevant information is stored as edges and they can be used conveniently to classify vertices. A boundary or a complex vertex is used to define a non-manifold case, while for the other three types, a vertex is defined to be surrounded by a complete cycle of triangles, and each edge that uses the vertex is used by exactly two triangles (a manifold case).

This algorithm deals with manifold models. Therefore, simple, interior edge and corner vertices are primarily handled. Boundary and complex vertices cannot be decimated here since they are non-manifold cases. Corner and interior edge vertices will be specially decimated so as to preserve the distinctive features of the object. For the four types of vertices handled here, their definitions are given in Table 7.3 (the threshold angles listed in the table are trial values and will be

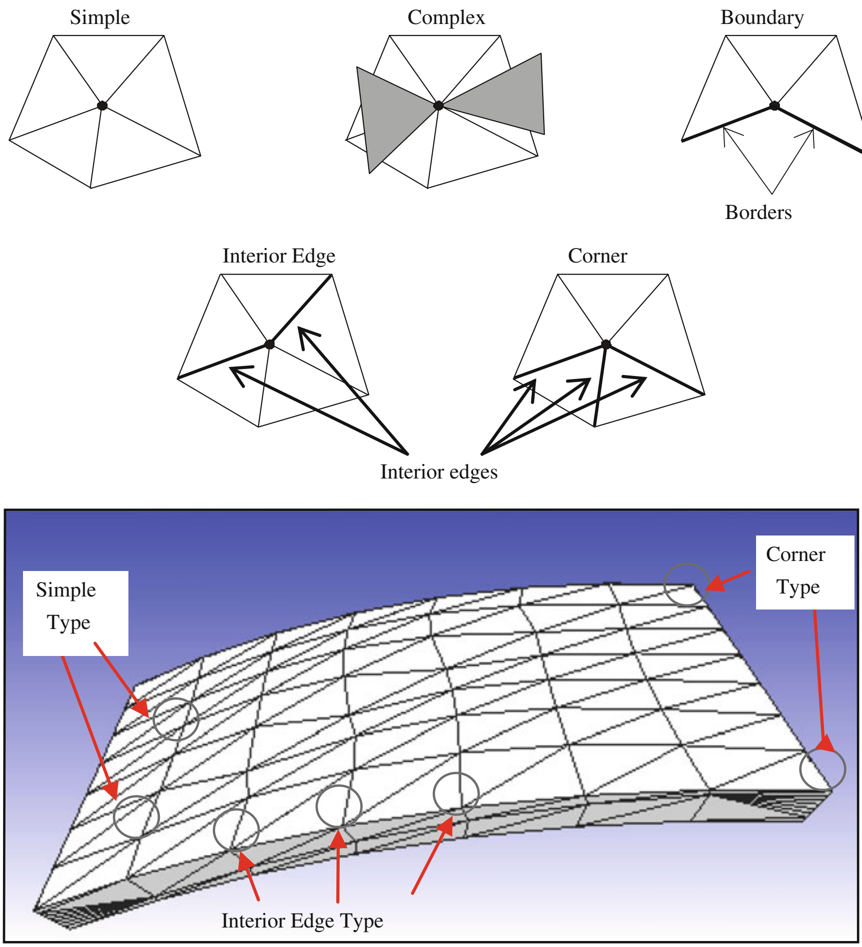


Fig. 7.6 Five types of vertices and illustrative examples

Table 7.3 Descriptions of the four types of vertices handled in the algorithm

Simple vertex type	Descriptions
Interior edge vertex	Vertex sharing 2 interior edges. Has only 2 pairs of adjacent neighboring triangles with normal angle difference $\geq 70°$
Corner vertex	Vertex sharing at least 3 interior edges; has $\geq$ 3 adjacent neighboring triangles with normal angle difference $\geq 70°$
Flat simple vertex	All adjacent neighboring triangles with normal angle difference $\leq 5°$ (or $10°$)
Non-flat simple vertex	Vertex that shares <2 interior edges and not all adjacent neighboring triangles with normal angle difference $\leq 5°$ (or $10°$)

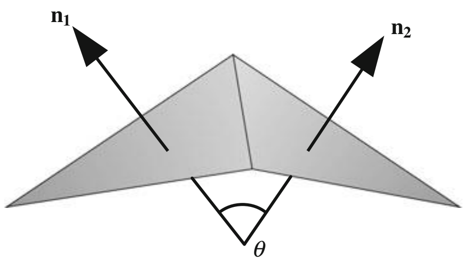


Fig. 7.7 Angle between normal of two neighboring triangles

adjusted adaptively to satisfactory values). In the table, a simple vertex is further classified as either a flat one or a non-flat one according to the geometric relationships between its neighboring triangles. To facilitate the handling process of the vertices, the triangular mesh in a VRML model being handled for simplification by the algorithm, which is named as the "detected triangle", must be checked with its neighboring triangles for detection of local planar region. The angle θ, between the normal vector of the "detected triangle" and each of its neighboring meshes is calculated, as shown in Fig. 7.7, using Eq. 7.1. This local region will be considered planar or flat if all of the angles are within a small, predetermined threshold angle. This threshold angle is arbitrarily set to be 5° initially. However, it can be revised adaptively during the decimation process.

$$\theta = \cos^{-1}\left(\frac{n_1 \cdot n_2}{|n_1||n_2|}\right) \tag{7.1}$$

7.3.3 Definitions of Criteria

To qualify an edge for collapse, two edge collapse criteria have been developed. Criterion 1 is based on the normal angles of triangles in a selected region to identify flat areas, while Criterion 2 works on triangles with poor aspect ratio. The type of triangles that will be qualified by a particular collapse criterion is shown in Fig. 7.8 (the non-simple vertex here is either an interior edge one or a corner one).

Criterion 1 is further subdivided into Criteria 1A, 1B and 1C according to the types of the vertices of the "detected triangle". From Fig. 7.8, Criterion 1A deals with the case that all of the three vertices of the "detected triangle" are simple and flat type, which means that its surrounding area is wholly flat along any direction. Criterion 1B deals with the case that one/two vertices are non-simple while the other one/two is/are both simple. Here, the requirement of Criterion 1B is met as long as at least one simple vertex is flat type. Moreover, only the collapse directions from flat to non-simple or between two flat simple vertices are allowed. Criterion 1C deals with the case that all of the three vertices in the "detected triangle" are simple but not all are flat, and it requires at least one of the vertices to

Fig. 7.8 Qualification of the type of triangles for a particular collapse criterion

be flat. Similar to Criterion 1B, for Criterion 1C, only the collapse directions from flat to other vertex types or between two flat vertices are allowed.

Criterion 2 basically deals with triangles with poor aspect ratio, regardless of the normal angles they make with all their neighbors. From Fig. 7.8, two types of triangles with poor aspect ratio are defined. Here, an aspect ratio is either the ratio (S/L) between the lengths of the shortest edge of a triangle over its longest edge, or the ratio (H/L) of the height of a vertex opposite the longest edge over the length of the longest edge. Whenever either aspect ratio is below a predefined small threshold ratio, Criterion 2 will select the appropriate edge and direction for collapse. Likewise, this threshold ratio can be changed adaptively during the decimation process. Furthermore, the evaluation of the S/L ratio takes precedence over the H/L ratio.

1. Definition of Criterion 1A

The starting point in the Criterion 1 series is the qualification judgment under Criterion 1A. For Criterion 1A to work, all of the three vertices of the "detected triangle" must be simple. A function, isVertexFlat, is called to check for the number of flat vertices in the "detected triangle". The definition of a flat vertex can be found from Table 7.2. If all the three vertices are flat, Criterion 1A is fulfilled. Hence, Criterion 1A will select the shortest edge of the "detected triangle" to collapse. This edge will be sent to a function, collapseEdge, to decide on the direction of collapse. This is determined by a surface area error function defined in Eq. 7.2.

$$Error\ Function : E_i = |A_i - A_0|\ where\ i = 1\ or\ 2 \tag{7.2}$$

where A_0 refers to the surface area of all triangles sharing at least one of the vertices of the selected edge, and Ai refers to the surface area of all triangles sharing the final vertex after vertex i is collapsed. Hence, the edge will be collapsed in the direction that will produce the smallest error value.

The surface error function employed here is to evaluate topological or visual difference between the simplified model and the original model, so as to optimally approximate the original mesh representation by using as little information as possible to significantly reduce the file size.

2. Definition of Criterion 1B

When only one or two simple vertices are found present in the "detected triangle", the algorithm will go to Criterion 1B. A function, termed getVertex-Type, will be called to evaluate the type(s) of the vertex that is/are present in the "detected triangle". In the case of only one simple vertex, this vertex will be evaluated by isVertexFlat. If it is flat, the direction of collapse to either one of the other two vertices (regardless of their type) will be determined by the same surface area error function in Eq. 7.2. Otherwise, the algorithm will be redirected to Criterion 2.

In the case of two simple vertices, each of the two vertices will be evaluated by getVertexType. When both of them are flat, the triangle will be qualified for decimation by Criterion 1B, and the shortest edge is selected for collapse. If both of these vertices belong to the shortest edge, collapseEdge is called to determine the direction of collapse. When only one of the two simple vertices is of flat type, the direction of collapse will be determined by the surface area error function in Eq. 7.2 to the vertex that is not flat.

3. Definition of Criterion 1C

Criterion 1C basically deals with triangles that have either one or two flat-type vertices when all the three vertices are simple. The edge to be collapsed will be based on the number of valid or flat vertices it has, which is calculated in Criterion 1A.

In the case of only one flat vertex, the edge will be collapsed from this flat vertex to either one of the other two vertices based on the surface area error function in Eq. 7.2. In the case of two flat vertices, the shortest edge will be selected for collapse. If both of these flat vertices belong to the shortest edge, the function collapseEdge will be called to determine the direction for collapse. If only one of these two flat vertices is in the shortest edge, this flat vertex will be collapsed to its opposite end.

4. Definition of Criterion 2

Criterion 2 is defined to deal with the triangles that have poor aspect ratio regardless of the edge length. Triangles with poor aspect ratio have been defined in Fig. 7.8. The algorithm will first check whether the S/L aspect ratio is less than the predefined small threshold value (such as 1/10 or 1/20). If this criterion is not met, it needs to proceed to check the H/L aspect ratio. A different threshold value may be employed for the H/L aspect ratio as part of the fine-tuning process.

If the S/L ratio is less than the threshold value, the type of the relevant two vertices that lie in the shortest edge (say V1 and V2) are checked by calling the function getVertexType. Then, the algorithm will process one of these cases specifically:

- When V_1 and V_2 both belong to the vertex set of {Interior Edge, Non-Flat, Flat}. If both of them belong to the same type, *collapseEdge* will be called to collapse the edge based on the *surface area error function* defined in Eq. 7.1.

- When $V_1 \in$ {Interior Edge, Non-Flat, Flat} type but $V_2 \in$ {Corner} type. In this case, V_1 will be collapsed to V_2 except for the case when V_1 is of Interior Edge type but V_2 is of Non-Simple type. In addition, the situation of V_1 and V_2 are exchangeable because of symmetry.

Similarly, if the H/L ratio is less than the threshold value, the vertex type of V3, which is the vertex opposite the longest edge with vertices V1 and V2, needs to be checked. Then, the Criterion 2 algorithm will process one of the following cases:

- When V3 is of Corner type. The vertex will not be decimated and will exit to the next "detected triangle".
- When V3 is of Interior Edge type. There are several cases to consider:

1. If both V1 and V2 $\in$ {Interior Edge, Corner} type, V1 type is checked whether it is the same as V2 type or not. If the two vertices are not of the same type, the Interior Edge vertex will collapse to the Corner vertex. If the two vertices are of the same type, Criterion 2 will exit and the algorithm will proceed to the next "detected triangle".
2. If either V1 or V2 $\in$ {Interior Edge, Corner} type, not both, V3 will be collapsed to the vertex that belongs to the set {Interior Edge, Corner}.
3. If both V1 and V2 $\notin$ {Interior Edge, Corner} type, i.e. both V1 and V2 $\in$ {Non-Simple, Non-Flat, Flat} type, Criterion 2 will exit and the algorithm will proceed to the next "detected triangle".

When V3 $\in$ {Non-Flat, Flat} type. The surface area error function will be called to determine the direction of collapse from either V3 to V1 or from V3 to V2.

7.3.4 Adaptive Threshold Parameters

From the preceding Sub-sections, a number of threshold parameters are used in the simplification algorithm. Whether a particular criterion can be fulfilled is affected by the threshold values set for these parameters. Four threshold parameters are primarily defined in the algorithm, namely, two threshold angles between two normal vectors of the adjacent planes to detect flat regions and feature edges, and two threshold values for H/L and S/L aspect ratios. If these values are small (except for the threshold angle to detect feature edges that is nearer to 90°) or 'strict', the triangles and vertices are less likely to fulfill the criterion conditions in the algorithm, and hence are less likely to be decimated. On the other hand, if these values are set to higher values, the model may be too coarse even though a higher level of decimation can be achieved.

When a particular round of decimation is low, the subsequent round is most likely to be even lower and sometimes the decimation level can be extremely low, say 1–3 %. It becomes inefficient if decimation is carried out further. Hence, the threshold values for these parameters need to be "relaxed" in order to achieve

Table 7.4 Scheme for step size used for adaptive threshold parameters

Threshold parameter	Threshold range	Factor f for decimation less than:		
		≤5 %	≤15 %	Otherwise
PlaneAngle	*5*–**25**°	1/2	1/3	1/4
FeatureAngle	**60**–*70*°	1/2	1/3	1/4
LimitingEdgeRatio	*0.1*–**0.25**	1/2	1/3	1/4
LimitingAspectRatio	*0.1*–**0.25**	1/2	1/3	1/4

NB: Initial values are italic and limiting threshold values are in bold

more decimation and make the execution more efficient. Therefore, adaptive threshold parameters have been proposed such that the threshold values will be adjusted based on the percentage of triangles removed in the last round of decimation. The threshold values (T) for a particular round (i) will be incremented by a certain step size (S) until the limiting threshold values (TL) for each parameter (k), as shown in Eq. 7.3a and 7.3b. The step size to be added is based on a scheme, which is a factor (f) of the threshold range for a particular parameter. The formula for determining the step size is shown in Eq. 7.4 and the scheme for the step size is shown in Table 7.4.

$$T_k(i) = T_k(i-1) + S_k(i) \tag{7.3a}$$

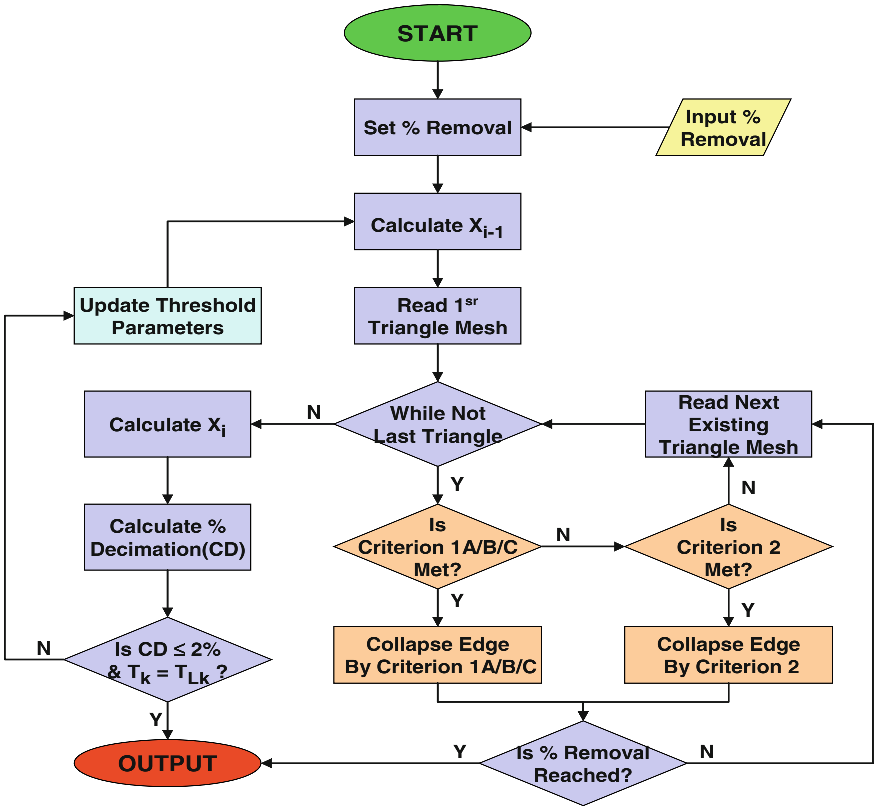
$$\& \quad T_k(i) \leq T_{Lk} \tag{7.3b}$$

$$S_k(i) = f \times ThresholdRange \tag{7.4}$$

In Table 7.4, the threshold parameter planeAngle is used for the angle between the normal vectors of two neighboring triangles to detect flat regions. FeatureAngle is the threshold parameter for the angle between two adjacent triangles for detecting feature edges. LimitingEdgeRatio is the threshold parameter for the S/L aspect ratio. LimitingAspectRatio is used for the H/L aspect ratio. Hence, the overall simplification framework in Fig. 7.5 has been modified to include the adaptive threshold parameters, and is shown in Fig. 7.9. A function updateThresholdParameters, as shown in the flowchart in Fig. 7.10, will be called after each round of decimation to update the threshold parameters based on the scheme presented above.

7.3.5 Refinement Process

Refinement is a process of restoring the details of the original geometry of a 3D model that have been lost during the process of decimation. The decimation process simplifies a model by deleting vertices in the original model and updating the model as given in the previous Sub-sections. During decimation, the data required to reverse the deletion process is stored in a reconstruction data file. This



X_i: Total number of Δs in round i
CD: Current % Decimation = $\%(X_{i-1}-X_i)/X_0$
T_k: Threshold parameter k
T_{Lk}: Threshold limit for parameter k

Fig. 7.9 The simplification framework with adaptive threshold parameters

data is used in conjunction with the decimated model to reverse the effect of each vertex deletion and get back the original model. This process is termed as refinement.

To explain the structures of the reconstruction data file, the implementation details of the edge collapse functionality is recalled here. Consider the set of triangles shown in Fig. 7.11a. T1 with vertices V1, V2 and V3 is the "detected triangle", One of its edges is collapsed as shown by the arrow, from V1 to V2. As a result of the edge collapse, triangles T1 and T2 are deleted from the model and triangles T3, T4 and T5 are updated, i.e., V2 replaces V1 in these triangles. The decimated mesh after the edge collapse operation is shown in Fig. 7.11b. While executing each of the steps described above, the data required for refinement is filled in ReconstructionRecord objects. At the end of the decimation process, these

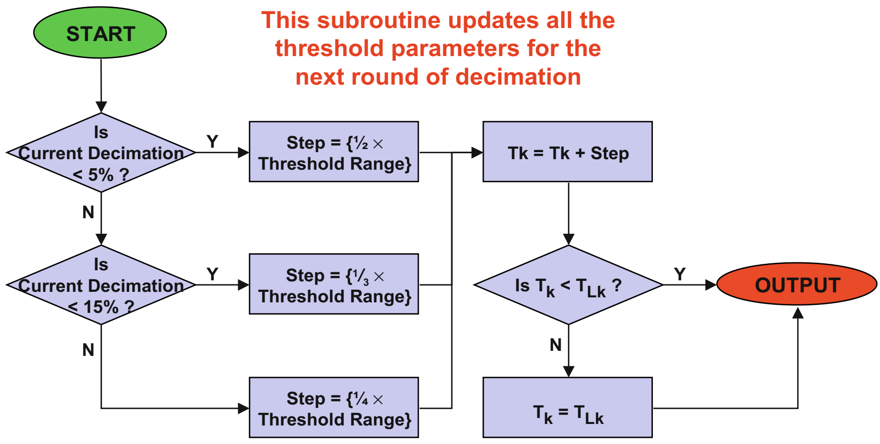


Fig. 7.10 Flowchart for *updateThresholdParameters* function

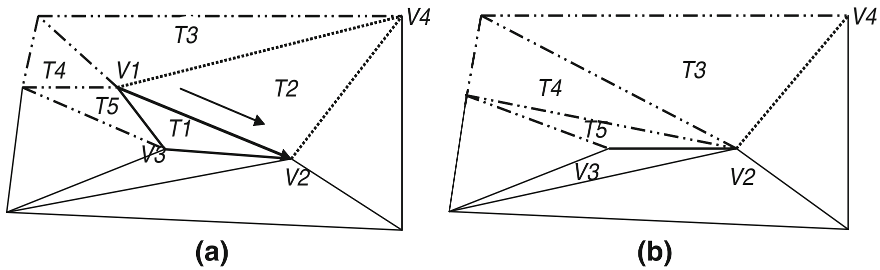


Fig. 7.11 The simplification process of a model. **a** Original model, **b** simplified model

objects are written to a file that is used along with the decimated model's VRML file to enable reconstruction of the original model. The last deleted vertex's ReconstructionRecord object is written first into the reconstruction data file and so on.

A brief description of the properties of a ReconstructionRecord object is given below.

deletedIndex: The index of the deleted vertex according to the original model. (In the above example, index of *V1*)
x, *y*, *z*: The coordinates of the deleted *V1*.
successorIndex: The index of the vertex that replaced the deleted vertex. (In the above example, index of *V2*)
updatedTriangleIndices: The set of triangles whose vertices were updated. (In the above example, indices of triangles *T3*, *T4* and *T5*)
deletedTriangleIndices: The set of triangles that are deleted as a result of the edge collapse. (In the above example, indices of triangles *T1* and *T2*)

deletedVertexPositions: The position of the deleted vertex in each of the deleted triangles. (Position is used in maintaining the order of the vertices in a triangle so that the direction of the normal of the triangle remains unchanged. The position is given as 0, 1 or 2, depending on its sequential order of the vertices describing the triangle in VRML syntax.)
successorVertexPositions: The position of the successor vertex in each of the deleted triangles.
deletedTrianglesOtherVertexIndices: A triangle is marked as deleted when it contains both *deletedIndex* and *successorIndex*. The third vertex in these deleted triangles is required to recreate the triangle. The third vertex for each of the deleted triangles is stored under this property. (In the above example, indices of *V3* and *V4* for triangles *T1* and *T2*, respectively.)

The corresponding original indices of the vertices and triangles of the decimated model are also stored as a part of the reconstruction data, along with the ReconstructionRecord objects. These indices are referred by the data in the objects of ReconstructionRecord. The refinement algorithm takes care of mapping these indices to corresponding vertices and triangles in the decimated model.

7.4 Comparisons of Algorithms

7.4.1 Visual Comparisons

The results of the algorithm can be measured by a graphical analysis of a model at the different stages and different settings of the decimation parameters. This analysis is similar to the procedure that was used by Schroeder et al. [4] in their study. Six different models, which have interesting shapes and contours, are used to test the flexibility of our algorithm. For each of the models, snapshot looks are taken at different stages in the decimation/refinement process.

1. Simplification with fixed threshold parameters

Given below in Fig. 7.12 are the images of the original and simplified models when the threshold parameters are set. The target decimation percentage was set to 1 % of the original size to get the maximum decimation possible with these threshold parameters.

2. Comparisons of fixed and adaptive threshold parameters

An adaptive mechanism is used to optimize the simplification process. In the mechanism, the threshold parameters are set to their initial values and are incremented towards the maximum/minimum limits in fixed steps. This incremental step sizes are governed by the percentage of the original triangles decimated with the parameters at their current value (which varies from the initial value to the maximum/minimum value). The simplification process in this case stops when the

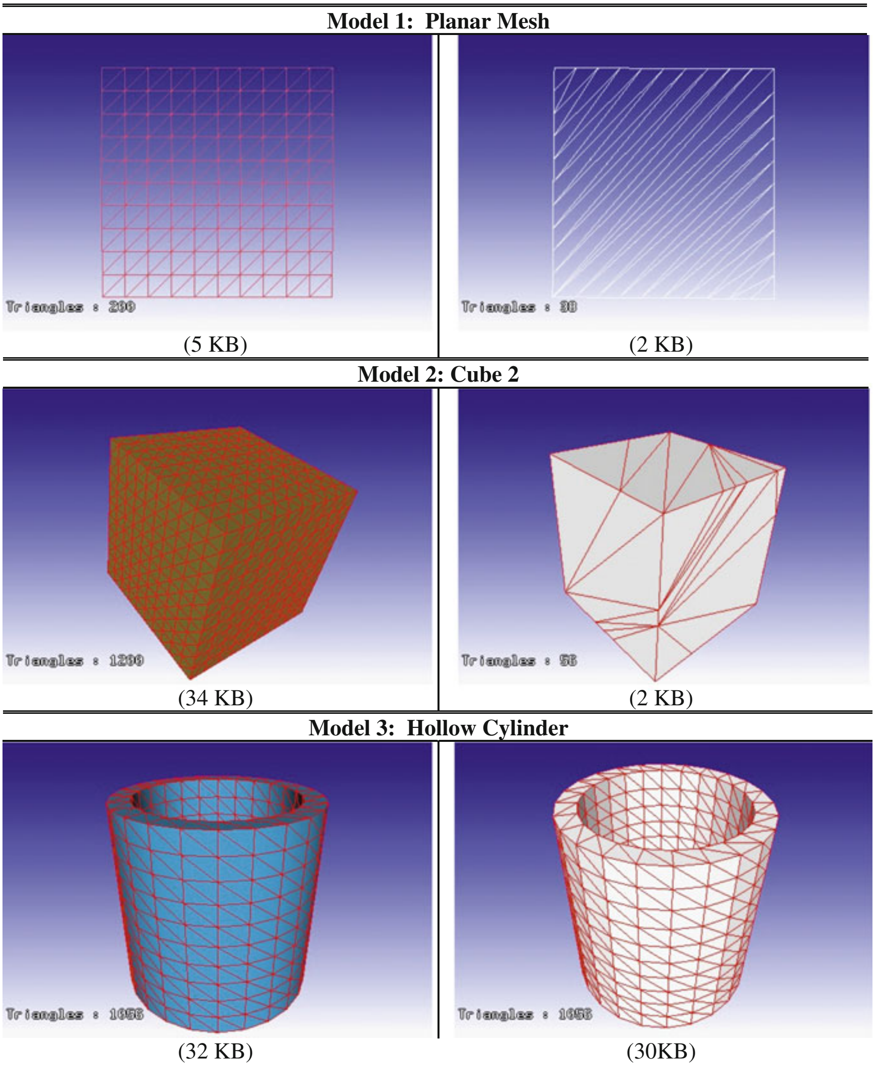


Fig. 7.12 Original models and those decimated with fixed threshold parameters

parameters reach their maximum/minimum values and the decimation in the round is less than or equal to the limiting percent. In Table 7.5, it is observed that the file sizes are smaller in the case of using adaptive threshold parameters.

Refinement reverses the effects of decimation and gets back the details in the original model (the relevant pictures are not shown here to save spaces). Given in Table 7.6 are the sizes of their reconstruction data files.

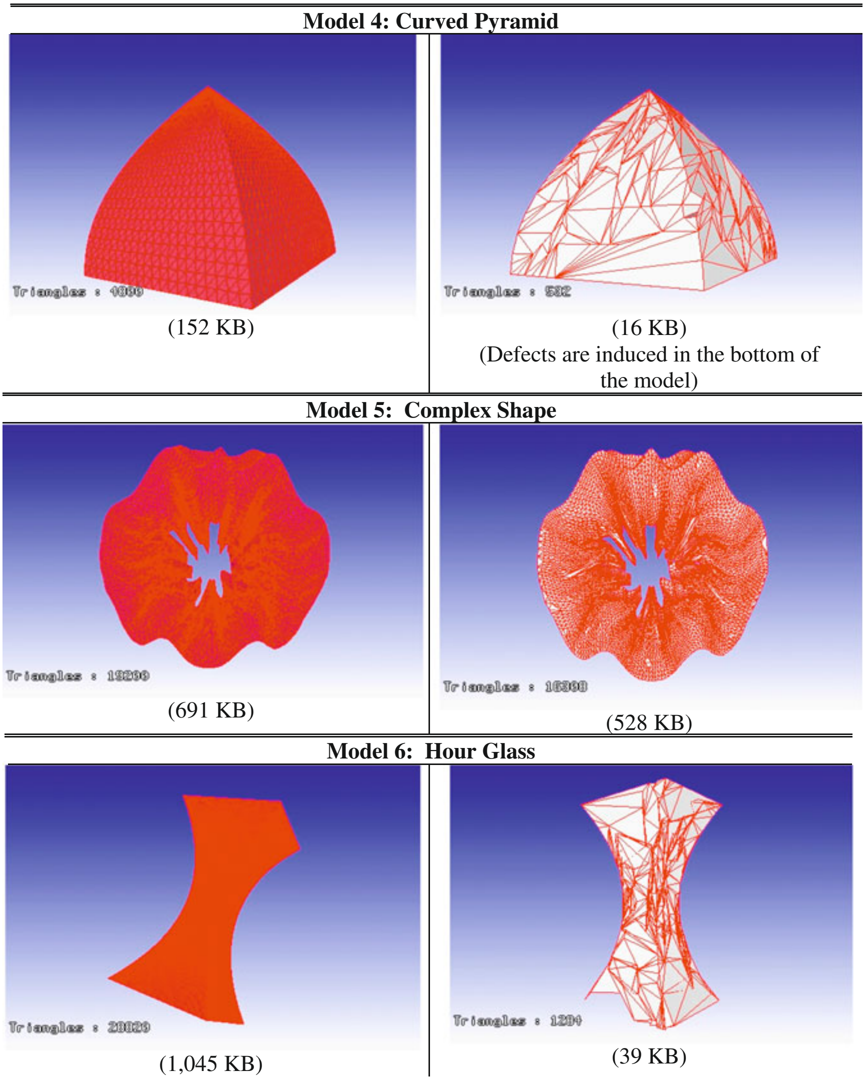


Fig. 7.12 continued

7.4.2 Comparison with Other Simplification Algorithms

Comparisons of six different mesh simplification algorithms were given in the work done by Lindstrom and Turk [12]. They used a tool called Metro [13] that was developed by Cignoni and Impoco. This comparison is given as a plot between the mean geometric error and the number of edges in the simplified

Table 7.5 The file sizes of the original and the simplified models

Model number	Original file size (KB)	Decimated file size (KB)	% file size decimated
(a) For fixed threshold parameters			
1	5	2	60
2	34	2	94
3	32	30	6
4	152	16	89
5	691	528	24
6	1,045	39	96
(b) For adaptive threshold parameters			
1	5	2	60
2	34	2	94
3	32	8	75
4	152	5	97
5	691	65	91
6	1,045	15	99

Table 7.6 The sizes of the simplified and the reconstruction files

Model no.	Original file size (KB)	Decimated file size (KB)	Reconstruction data file size (KB)
1	5	2	2
2	34	2	18
3	32	8	20
4	152	8	35
5	691	65	164
6	1,045	15	242

model. A similar plot is given between the maximum geometric error and the number of edges in the simplified model.

Since the source codes to these algorithms are not available and the results given by Metro [13] were much below the scale of the plots, we compared our results with that of another simplification algorithm, developed by Garthwaite and Reposa [14], which source code is available to us (called the WPI algorithm in the following content). The documentation of their work gives a comparison between their work and the other six mesh simplification algorithms. Hence, through comparing with them, we indirectly compare our work with the other six algorithms. These plots are given in Fig. 7.13.

The Stanford bunny model is used as the original model and it is decimated to different levels. The number of edges in each of the decimated models is calculated. The VRML files of the original model and decimated model are converted to Simple Model Format (.smf file) [15], as Metro works on .smf files but not on VRML files. Their geometric error values are found using Metro. Similar decimation, file conversion and error calculation are performed on the bunny model using the WPI algorithm. Figure 7.14 shows the plot between mean geometric error and the number of edges for the WPI algorithm and our algorithm, whereas

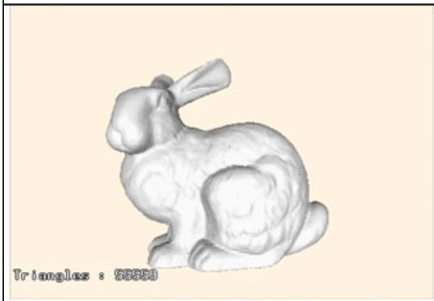
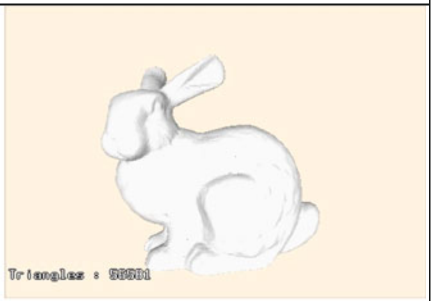
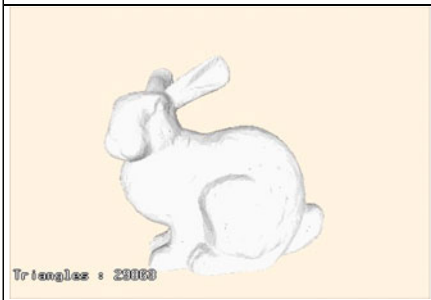
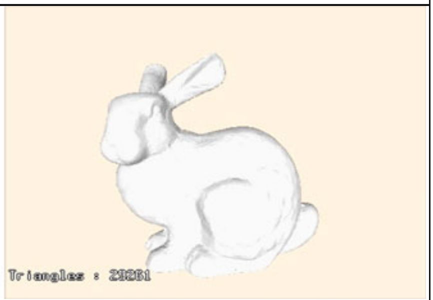
Our algorithm	WPI algorithm
Model 1: 80 %	
 (55559 triangles)	 (56581 triangles)
Model 2: 43%	
 (29863 triangles)	 (29261 triangles)

Fig. 7.13 Visual comparison of the developed algorithm and the WPI algorithm

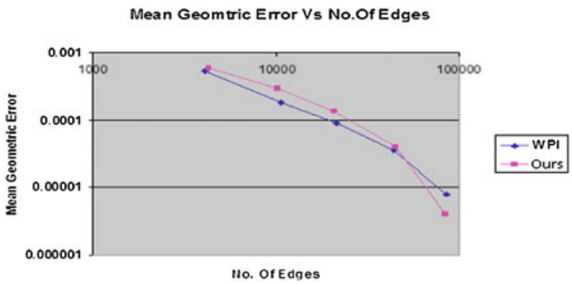


Fig. 7.14 The mean geometric error of our algorithm and WPI algorithm

Fig. 7.15 shows the plot between maximum geometric error and the number edges in the decimated model.

It is clear that both the algorithms give almost the same maximum geometric errors and the mean errors are slightly less for the WPI algorithm. In the comparisons of the WPI algorithm by Garthwaite and Reposa [14] with the six algorithms presented in Lindstrom and Turk [12], it shows that the values of geometric error for the WPI algorithm are less than the other six. Since our results are very

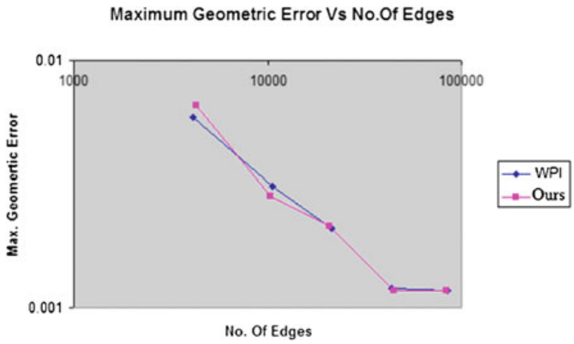


Fig. 7.15 The maximum geometric error of this algorithm and the WPI algorithm

close to the results of the WPI algorithm, we can claim that our geometric error values are less than the six algorithms in Lindstrom and Turk [12]. Hence, our algorithm is more effective in terms of less geometric errors.

In our algorithm, comparison of each triangle for evaluation of the planar criteria and the function to check the type of a vertex are the most time consuming steps in the execution of the decimation program. Since every triangle is compared with its neighbors for these two steps, this main operation is of the order 2. Other operations like edge collapse are of the order 1 and are proportional to the number of triangles. Therefore, the time complexity of our algorithm presented can be approximated as an O (n2) algorithm.

7.5 Conclusions

In a Cloud enabled collaborative system, one of the main impediments is the relatively slow transferring of 3D visualization data for application software packages over the Internet. 3D streaming technology can effectively optimize the sharing of the 3D visualization design and manufacturing models through decimating the original model and generating a series of simplified models for the original model, and then the reconstruction data to get back the details lost during decimation. Transferring a series of simplified models step by step will fulfill the client's request to have efficiently incremental visualization. Simplified models have kept the important features of the original model and yet is much smaller than the original model to implement incremental data transferring.

In this chapter, a new geometric simplification algorithm, which forms the key element of the streaming technology for 3D design and manufacturing visualization data, has been developed. In this algorithm, based on the characteristics of the vertex decimation approach and edge collapse approach, two criteria have been proposed to control the collapse process for edges in 3D models to reduce the information. In the meantime, a mechanism of adaptive threshold parameters has been developed to enhance the adaptability of the algorithm for various applications. The follow-up refinement can realize a whole streaming process. Applications on case studies, which are typical examples from related works, show the good performance and potentials of the algorithm from the perspectives of efficiency, adaptability and robustness.

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Chapter 8
Designing by Services: A New Paradigm for Collaborative Product Development

Hongwei Wang and Heming Zhang

Abstract The design and development of complex products entails the collaborative work of multidisciplinary and geographically distributed teams. The collaborative work largely depends on the effective sharing and integration of information and computing powers in a distributed environment, and thus raises the need of supplying flexible and accessible information for the next generation design systems. Current design systems and tools are mainly focused on specific aspects such as design, analysis, and manufacturing while the need of integrated and collaborative development is not yet addressed. In this research, a paradigm of designing by services is envisaged which is aimed at supporting collaborative product development by integrating information and computing powers provided as services by organizations with different expertise. Such a paradigm requires a flexible architecture and the support of information technologies as it involves a large amount of complex information about products, processes, and people. This book chapter presents a paradigm of designing by services, describes the devising of a service oriented architecture for the design systems for this paradigm, discusses the key enabling technologies involved, and introduces the development of a collaborative simulation using service oriented computing as a case study of software systems implementation.

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8.1 Introduction

Engineering design is a complex process in which designers iteratively develop and optimize solutions for technical problems by applying their scientific knowledge. This process is driven by market needs and constrained by available information, human resources, and investment. Wallace identified a number of trends for modern product design and development: increasing globalization; greater competition; shorter life cycles; increasing complexity of processes and products; large distributed design teams; reliance on Information Technology (IT); explosion in available knowledge; and urgent need for sustainable design [1]. As a consequence, the effective management of design processes should be performed to support distributed design teams in developing high-quality, low-cost in terms of both money and time, and sustainable design solutions, and thus raises the need of a significant body of fundamental design research. Some of the popular areas of research include the development of Computer Aided Design (CAD) tools to improve effectiveness and efficiency of producing design solutions, the use of Computer Aided Engineering (CAE) tools and advanced computing to identify design flaws at early stages of the design process to reduce risks, the application of Computer Aided Manufacturing (CAM) tools to speed the transformation of design information into manufacturing information and ease the planning of manufacture, and the management of information/knowledge to improve decision-making by supplying relevant and useful information. These areas are focused on particular aspects of the design work and the resultant tools cannot support large distributed teams. Nevertheless, current research facilitates managing design/manufacturing information electronically and opens up the opportunities for further work supporting distributed design.

Hence, design systems are required for supporting the whole design process rather than only particular aspects such as geometric models and manufacturability analysis. Some studies have been done on studying the next-generation design systems. For instance, Szykman and Sriram indicated that the next-generation product development systems will be distributed and collaborative [2]. A resultant paradigm is called Collaborative Product Development (CPD) which is aimed at developing products by incorporating advantageous resources and making collective decisions amongst distributed teams. A distributed CPD system is particularly helpful for modern product development which is being done more often by geographically and temporally distributed design teams [3]. As a paradigm for supporting the whole design process, CPD involves many issues and requires a large amount of research work. A number of issues have been taken into account in the development of CPD systems, e.g. architecture of information system, team management, communication tools, engineering applications, product geometric representation, integration with CAD/CAE/CAM tools, and knowledge representation [4]. Existent CPD systems mainly focus on supporting activities such as accessing and visualization of design data and design of components and assemblies [4].

The key issues in CPD include system integration and interpretability [3], communication and information representation [4], and project management [4]. In the authors' opinion, there are three challenges for the implementation of CPD. The first one is the sharing of information. Information updated by different teams may be in different formats and have different meanings, which requires the effective integration of information across different infrastructure/systems. In the context of cross organization collaboration, information may need to be kept confidential and only provided as part of a functional service. The second issue is the integration of computing powers as computing is very common in engineering design. This not only requires computing powers to be easily accessible but also involves the coordination of computing processes to perform complex analysis tasks. Thirdly, effective management of the design process is essential as CPD involves various people, processes, and resources. To address these challenges, a flexible and effective architecture is needed and more importantly enormous IT support is required. Hence, provision of data, integration of information, and functional integration of computing resources should all be managed by professional solutions and the technical details involved should be kept away from team members of distributed CPD as much as possible. A new paradigm of Designing By Services (DBS) is proposed to address the challenges, which emphasizes the provision of professional solutions as services and the integration of these services to undertake complex information accessing/integration and the collective use of computing.

The remainder of this chapter is organized as follows. In Sect. 8.2, the literature related to CPD, the next-generation engineering software, and advanced computing technologies is reviewed. In Sect. 8.3, we introduce a new paradigm of DBS for CPD, which is supported by service oriented computing. In Sect. 8.4, key enabling technologies for the proposed paradigm are discussed in detail. In Sect. 8.5, the development of a collaborative simulation system is described as a case study for the implementation of tools and systems for the paradigm. Finally, discussions and conclusions are given in Sect. 8.6.

8.2 Literature Review

Literature reviewed in this research is centered on methods and tools for CPD in a distributed environment. A few keywords can be identified to describe the features of current research on CPD, namely collaboration, integration, information, and computation. Specifically, collaboration is the most typical feature of CPD and involves the methodology of performing development tasks by incorporating the advantageous resources of parties in collaboration. Integration is a key feature of CPD and determines how well the resources can be incorporated in a distributed environment, involving both development methods and computing technologies. Information is dealt with in CPD to better produce, share, use and reuse information and knowledge among parties in collaboration. Lastly, two ways of using computation exist in CPD: the first is the use of computing technologies to support

CPD; the second is to support computation in a distributed environment to perform analysis for CPD. This section is aimed at describing the state-of-the-art CPD research in terms of these four areas.

8.2.1 Distributed Collaborative Product Development

CPD is a methodology of integrated and collaborative design for addressing the requirements raised by the increasingly complex nature of modern product development [5–7]. Hence, system integration and group collaboration can be identified as the key issues in CPD, which have been researched widely [8, 9]. Computer Supported Collaborative Design (CSCD) can be dated back to the 1980s when Computer Supported Cooperative Work (CSCW) became a popular research topic and began to be applied to the engineering domain [10]. In the 1990s, the emergence of Web related technologies greatly promoted CSCD which hence rapidly became a hot topic from the beginning of the 21st century with the support of integration technologies such as CSCW, Web, and agent [10]. Li et al. pointed out that two types of collaboration were mainly found in CPD, namely horizontal collaboration and hierarchical collaboration [8]. The former concerns the cooperation of team members from the same discipline to carry out a complex task in either a synchronous way or an asynchronous way while the latter emphasizes the cooperation between upstream design activities and downstream activities such as manufacturing [8].

Essentially, horizontal collaboration aims to support the collective effort of team members to resolve a joint task. Research on horizontal collaboration can be found in the solving of a number of problems in the design process, e.g. assembly design [11, 12], product modeling [13], and process planning [14]. Major issues of horizontal collaboration include the sharing of information between team members and the licensing of team members to operate on specific pieces of information so as to protect proprietary information and address conflicts. For example, Lee et al. developed a collaborative intelligent CAD framework on the basis of a core design history algorithm that is used to reason about which team member will have the ownership on design models [15]. Hierarchical collaboration, by contrast, is focused on the solving of design problems by team members with different expertise. Research work on hierarchical collaboration can also be found in recent literature. For instance, Park and Seo developed a life-cycle assessment system for evaluating environmental impacts of different design alternatives [16]. Curran et al. proposed an integrated digital design paradigm to facilitate design decision making by taking into consideration manufacturing and cost issues [17]. Apart from the pieces of work mentioned above, other issues of CPD have also attracted the attention of researchers, e.g. interface design and control methodology for CPD tools [18], the use of ontology and semantic technologies for effective and 'meaningful' integration [12, 19], and communication technologies for CPD [20–23].

8.2.2 Knowledge and Information Management

Information representation and sharing is fundamental to CPD as it involves objects and their relationships in a design task. The ultimate goal of representing and sharing information is to make it transferred to, and accessed by authorized users or computer systems, and, clearly, the correctness and effectiveness of CPD is largely determined by it. Li et al. summarized that information that should be shared in CPD involves visualization, products, project management, etc. [8]. Szykman et al. proposed a product model to make design information assessable to users in a Web-based system [24]. The sharing of information involves two levels: the level for system integration and the level for human-understandable information/knowledge. For the latter, a number of integration methods and technologies have been developed, e.g. Web, agent, and CSCW [9]. Shen et al. developed an agent-based integration framework for collaborative intelligent manufacturing [21]. Chu et al. designed and implemented a 3D design environment where information with different levels of details is transferred to different design engineers [25]. Shen and Grafe developed a VR-based virtual prototyping method to support multidisciplinary communication between different systems for performance analysis [26]. Liu et al. proposed a paradigm of composing services to integrate loosely coupled software components which involves detailed design of data and control flows [22].

The sharing of information for information/knowledge management has also been widely studied. For instance, Rodriguez and Al-Ashaab proposed a knowledge driven system architecture to facilitate the provision of knowledge for CPD [4]. Zha and Du developed KSDMME, a Web-based knowledge-intensive distributed module modeling and evaluation framework, to link distributed, heterogeneous knowledge-based design models and tools, and assist designers in evaluation and decision-making [27]. Robin et al. investigated the knowledge exchanged and shared during CPD design processes and identified design context as a key element for supporting design processes and knowledge exchange [28]. It is noteworthy that the two levels of information/knowledge for CPD discussed above do not necessarily mean that current research only focuses on a particular level. In fact most of the work mentioned above was targeted for both of the two levels albeit this was not explicitly stated. Some researchers did make the purpose explicit. For example, Kim et al. developed an ontology-based assembly design method which was aimed at making heterogeneous modeling terms semantically processed by both design collaborators and intelligent systems [12].

8.2.3 Multidisciplinary Simulation and Complex Computation

Simulation technology has been widely applied in industry and plays an increasingly important role in design validation and verification [29, 30], which raises the need to support the simulation and complex computation used in CPD. The development of complex engineering systems, e.g. mechatronics, involves multiple disciplines such as mechanical, electronic, and control, and requires a multidisciplinary approach. The research in multidisciplinary simulation has been proposed by many researchers to go beyond the studies of single-domain simulation [31]. For example, Samin et al. proposed to use Multiphysics modeling and optimization for mechatronic multi-body systems [32]. The use of multiple simulators to perform complex simulation and computation has also been proposed [33], raising the need of studying multidisciplinary collaborative simulation for CPD [6, 29]. In this sense, simulation models and computation resources should be provided as assessable services and integrated at run-time to perform complex simulation tasks. Shen and Grafe developed a VR-based virtual prototyping system for mechatronic system development, which involves the communication between multidisciplinary models [26]. Xiang et al. developed an agent-based composable simulation system for fluid power system [34]. Research has also been done to make computation resources and legacy models/codes assessable as services for effective use and re-use in current/future development tasks. For example, Roselló et al. proposed a component framework to reuse proprietary computer-aided engineering systems/models [35]. Liu et al. proposed a method of composing services to facilitate the integration of loosely coupled software components [22]. Tsai et al. developed a service-oriented modeling and simulation framework for rapid development of distributed applications, which has a focus on the flexible and effective integration of simulation services to build complex applications [36].

8.2.4 Distributed Computing Technologies

The application of distributed computing technologies such as Web, Web Services, Grid, and cloud computing in engineering has been a hot topic since the inception of CPD research due to their powers in distributed communication and system integration [9, 10]. For example, Wang et al. developed a Web/agent-based multidisciplinary design optimization environment [37]; Cheng and Fen developed a Web-based distributed problem-solving environment where computational codes can be accessed and integrated to solve engineering problems [38]; Jiang et al. proposed a Web services and process-view combined approach to the process management in CPD [20]; Fan et al. devised a distributed collaborative design framework and used Peer to Peer (P2P) and Grid technologies for its implementation [39]. Interoperability between CAE software tools is of significant importance to achieve greatly increased benefits in a new generation of product development systems [3]. Lots of work has been done on the system integration and collaboration technologies, e.g. Web, agent, Web Services, and semantic Web, and open standards and commercial tools have already been available [9]. The development of infrastructural technology for CPD systems has also been researched to support distributed integration and collaboration with improved effectiveness and efficiency.

These technologies have also been applied to the development of distributed multidisciplinary simulation systems. Reed et al. developed a Web-based modeling and simulation system which was applied to the aircraft design process and argued that such a system could improve the design process [40]. Wang et al. proposed to develop a multidisciplinary modeling and simulation platform which can support the running and integration of simulation services on the Internet [29]. Byrne et al. reviewed recently research on Web-based Simulation (WBS) and its supporting tools and concluded a number of advantages of WBS, including: easy use; collaboration features; license and deployment models, etc. [41]. One of the important enabling technologies of WBS is middleware which enables different modules in a WBS to interoperate [41]. Some middleware technologies, e.g. CORBA, Web Services and the High Level Architecture (HLA), have been used in developing collaborative simulation systems for engineering design [6, 29]. Among these technologies, Web Services is a very promising technology for system integration on the Web whilst the HLA is an important and heavily researched standard for distributed simulation [41]. Two ways have been identified and researched for the integrated use of Web Services and HLA, namely developing HLA enabling tools using Web Services and making HLA federation to interoperate with other software applications [23, 42, 43].

8.2.5 Discussion

In summary, lots of methods and infrastructural technologies have been developed and applied to support system integration and collaboration for CPD. In particular, four features that have been widely studied can be identified from current CPD research, namely collaboration, integration, information, and computation. However, current research mainly focuses on specific problems in CPD with little work on the development of a widely used tool although it lays a good foundation for further work on CPD by demonstrating that some particular methods are viable and some particular technologies are useful. The potential of CPD is not yet fully explored and new methods/paradigms should be developed and new technologies should be exploited. A number of key issues should be well addressed in future work. Firstly, interoperability plays an important role and shall be well studied to support the integration of complex and heterogeneous systems. Flexibility, effectiveness, and security/privacy are central requirements for system integration. Secondly, a CPD paradigm should allow multiple systems/tools/platforms to work for different purposes and users should be able to select favorite ones [10]. Third, simulation and high-performance computation are essential part of complex product development and should be integrated and supported in CPD. Last but not least, the technical details of collaborative work and system integration should be kept away from users as much as possible. Based on the above discussions, the authors believe that a useful CPD system should be based on the provision of a set of tools/platforms by professional parities and complex development processes should be carried out by selecting part of the professional services. This allows us to envisage a new paradigm of DBS supported by CPD methodology and advanced computing technologies.

8.3 Designing by Services Supported by Service Oriented Computing

8.3.1 Designing by Services

Nowadays, the design and development of products is becoming increasingly complex and requires effective management to ensure the successes of projects. At the corporate level, companies should make strategic plans and provide supportive environment to encourage the application of advanced design methods and the adoption of creative and innovative enterprise cultures. At the project level, necessary resources and relevant personnel should be allocated and systematic design processes should be employed to reduce the number of iterations and improve product quality. Moreover, design tasks are increasingly carried out in a collaborative way due to limited resources and different expertise of individual companies. A scheme of collaborative product development in the Internet distributed environment is shown in Fig. 8.1, where teams with different roles such as designers, managers, and analysts in a project are based in different locations and communicate with each other on the Internet though this is not explicitly shown in the figure. It is noteworthy that each role shown in the figure may also involve several teams rather than just one. For example, designers may come from several teams based in different locations and work collaboratively on the same project.

In the centre of Fig. 8.1 is the iterative design process which is adapted from the classic process proposed by Pahl and Beitz [44]. The input of this process is market needs whilst the output is the definition of detail design solutions. There are several roles identified in CPD, namely marketing people, system analysts, project managers, designers, pattern makers, and others (e.g. finance people and experts on environmental impacts analysis). People with different roles and from different locations work together to make key decisions until optimal solutions have been developed, and in this way, issues about project management, business analysis, manufacturing, environmental impacts, etc. can be addressed in the early stages of design. As mentioned above, different teams may get involved in a single step of

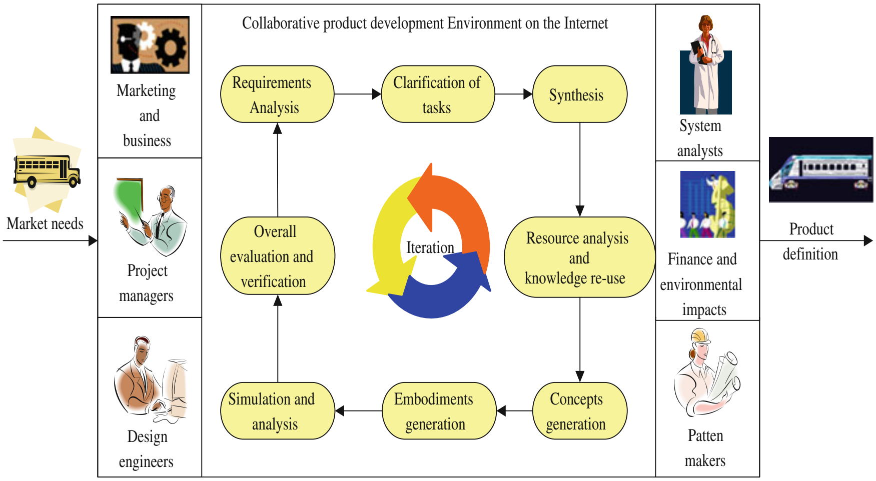

Fig. 8.1 A scheme of collaborative product development

the process. For example, concepts/embodiments generation can be done by teams with expertise on different disciplines such as mechanical, control, and hydraulics. Apart from the core design steps such as clarification of tasks and concepts/embodiments generation, other key tasks in complex product design are also included, e.g. requirement analysis, simulation, and knowledge re-use. The typical features of CPD discussed in Sect. 8.2 are reflected in the process. Firstly, collaboration is required for nearly all the tasks. Second, integration is clearly desirable as information sharing and exchange is essential in the scheme. Third, information is important for supporting analysis, synthesis, and project management. Lastly, computation can also be used in other tasks such as computational synthesis and simulation analysis.

A number of CPD characteristics can be identified from the scheme. Firstly, it involves a large amount of information which needs to be shared and exchanged among team members. Second, it depends on the use of various tools such as CAD packages and information management tools, and requires great IT support for team collaboration and system integration. Third, it concerns lots of professional knowledge, e.g. simulation and environmental impacts analysis. Fourth, the scheme involves an iterative process and requires seamless integration between different stages, raising the need for process management. Moreover, privacy and security is a key issue in this scheme as the sharing of information may be cautious. Therefore, lots of tasks need to be carried out by professional teams to undertake collaboration and accomplish design objectives. These tasks should be made clear at the beginning of a project and the design system should be flexible, effective, and secure. It is thus useful for different parties in collaboration to specify what kind of services they can offer and more importantly a professional team should work out the integration of these services through integration services. As such a paradigm can be envisaged to undertake complex design and development tasks by finding and using professional services which enable effective integration and allow team members only focus their portion of work. Examples of these services include services for producing design, services for supplying requirement information, services for computation, and services for complex integration.

8.3.2 A Service-Oriented System Architecture

As discussed in the last section, the DBS paradigm depends on various services provided by parties in collaboration. These services are developed and maintained by parties with relevant professional knowledge, operate in different locations, and will ultimately be integrated in a design system which offers graphical interfaces for users to carry out design tasks. Such a paradigm actually entails lots of research work and two issues need to be addressed in the first instance for its successful implementation. The first issue is the identification of various services to make clear division of tasks and achieve cost-effective system integration. This issue thus requires an analysis of the roles and tasks in the scheme shown in Fig. 8.1. The second issue is the computing technologies to be employed to underpin the paradigm, which greatly influences the performance of design systems. This section is aimed at understanding the services needed for CPD and their implementation technologies.

A service-oriented architecture is shown in Fig. 8.2, which offers a reference framework for the software systems for DBS. Broadly, any task performing provision of information, computation, and integration of any two processes can be viewed as a service in CPD. In the proposed DBS paradigm, there are eight kinds of services as shown in Fig. 8.2. Information services involve the processing and provision of information such as market needs, design specification, and manufacturing resources, which are aimed at facilitating decision-making in design. This research distinguishes knowledge services and information services in that the former are mainly used to capture, store, and supply pieces of design knowledge. In this sense, knowledge is viewed as a kind of intellectual property rather than plain information, e.g. how to process materials and why a component was designed in the way it is. Process services are used to manage the configuration and execution of complex CPD processes. Integration services are mainly used to facilitate information integration between two systems and manage possible changes in the systems involved. Security services, as the name suggests, mainly deal with security issues. Security issues are not only about the protection of information but also concern the cautious sharing of information between different parties in collaboration. Design services are developed to facilitate the execution of design tasks such as concepts generation and evaluation, drawing production, and synonymous operation on CAD models. Simulation services specifically refer to the components in multidisciplinary simulation for complex problems, which are integrated at run-time to evaluate the performance of a

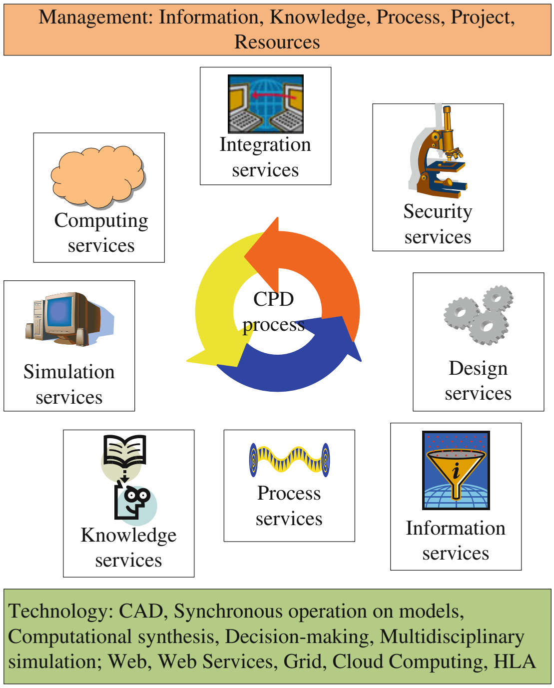

Fig. 8.2 A service-oriented architecture for designing by services

proposed solution at the system level. Some computations used in the design process are also provided as simulation services, e.g. computational synthesis and reasoning on design data.

8.3.3 A Scenario of Designing by Services

To explain how the service-oriented architecture supports DBS, a scenario is illustrated as follows on the basis of the key stages of CPD. Tasks in the design process and relevant services involved in each individual task are shown in Table 8.1 where words in brackets are used to describe the purposes and functions of the services.

It is noteworthy that process services are actually needed in nearly all the tasks and they are only shown in the first task for the sake of brevity. At the beginning of the design process, team members interact with a design system which then starts the process through process services and grants members different accessing rights. The initialization of computing services and integration services is also done at this stage. At the stages of requirements analysis and tasks clarification, information services are mainly used to facilitate decision-making and store important information such as design specification and project management for

Table 8.1 CPD process stages supported by services

Design tasks	Services involved in the tasks
Starting the design process and joining virtual working environment	Process services (monitoring and controlling the whole process), security services (licensing of access and granting of ownership), computing services (establishment of distributed working), and integration services (sending relevant information to other systems)
Requirements analysis	Information services (provision of requirement information for decision making)
Clarification of tasks	Information services (recording design specification and informing relevant members)
Synthesis	Simulation services (computation), Knowledge services (supply of knowledge for understanding problems and making decisions), and Integration services (sending results of synthesis over to design services)
Resource analysis and knowledge re-use	Information services (information about resources) and knowledge services (knowledge about previous projects)
Concepts and embodiments generation	Design services (supporting the creation of solutions and production of drawings), information services (provision of relevant in information response to queries), knowledge services (supply of knowledge about specific topics and previous projects in response to queries), integration services (supporting collaborative work and sending design information for simulation)
Simulation analysis	Simulation services (creation and encapsulation of simulation models, running of multidisciplinary simulation), integration services (integration with design services and sending results for overall evaluation)
Overall evaluation and verification	Information services (provision of relevant information), simulation services (obtaining and analysing simulation results), and integration services (sending evaluation results to relevant systems)

later usage. For synthesis, computation may be used to explore the design space and thus simulation services are involved. In addition, synthesis also requires relevant knowledge for designers to understand design problems and generate ideas whilst the resultant synthesis information needs to be kept for use at later stages. Therefore, knowledge and integration services are also needed. As the name suggests, resource analysis and knowledge re-use requires information/knowledge services. Concepts/embodiments generation is the core of the design process and involves design services and other supporting services for information, knowledge, and system integration. Clearly, simulation services are needed for simulation analysis for which integration services are also essential as simulation results should be sent to other systems for further analysis and comparison. The last task of overall evaluation depends on simulation results and sufficient information about manufacturing, environmental impact, etc., and thus should be supported by simulation services, information services, and integration services.

8.4 Key Enabling Technologies for Designing by Services

A paradigm of DBS is described in the last section, with eight kinds of services identified and a service-oriented architecture developed. A scenario is also introduced to illustrate how the services are used in the design process. The eight services have different focuses and clearly require the support of many technologies which not only concern product design and development but can also include distributed computing technologies. In this section, a few enabling technologies will be discussed to underpin the implementation of software systems for DBS, as well as to identify promising directions for further research. These technologies are discussed in detail in the remainder of this section.

8.4.1 Distributed Computing Technologies

Apart from the eight kinds of services, management and technology are two important issues in the service-oriented architecture. On the one hand, the development of this architecture is aimed at supporting effective management of CPD and thus the management of information, knowledge, resources, processes, and projects should be taken into account in the design of services. On the other hand, technologies are also important for CPD in a distributed environment. Some specified design technologies such as CAD, decision-making, computational synthesis, and multidisciplinary simulation should be well considered. Moreover, distributed computing technologies should also be utilized to support the service-oriented architecture. In this research, Web, Web Services, Grid, Cloud computing, and the HLA are identified as promising technologies. Specifically, the Web can be used to implement Web-based system which offers a virtual working environment for CPD. Web Services can be employed in a number of ways, e.g. development of information and knowledge services, implementation of process and integration services, and encapsulation of simulation and design services. The Grid can be used for sharing computation resources (i.e. simulation services) and supporting provision of design services. Cloud computing can be applied for massive storage of information/knowledge, implementation of security services, and the shared use of tools/systems/platforms. These technologies have different features and powers, and in practice they should be chosen based on system requirements and available budgets. Detailed discussions on these technologies can be found in [9, 41].

8.4.2 Design Data Exchange and Synchronous Operation of Designers

CAD tools are widely used in engineering design, which are increasingly powerful and can improve the effectiveness and efficiency of model creation and drawing production. Modern CAD packages may also have advanced functionalities such as kinematic analysis, knowledge capture and re-use, and integration with CAM tools. In CPD, design solutions are created collaboratively by distributed team members who may use different CAD packages. Moreover, synchronous operation on CAD models is required when several teams work on the same component/assembly. Therefore, design services need to address two issues. The first is the use and integration of multiple CAD tools and the exchange and management of design data. CAD packages provided by different vendors may rely on different methods for geometric information representation, raising the need of studying the exchange of CAD models among different teams without loss of key design information. This means that a function of design services is to obtain design information from one site and accurately transform it into a data format which can be accepted by another site. Some research has been done in this area but further work, nevertheless, is still necessary to deal with complex information.

The second issue is the synchronous operation on design models. This is critical for online collaboration in which several teams work on the same model. The key to this issue is the granting of ownership to a team, i.e. only one team can operate on a model at a short period of time. If all the teams are waiting for each other, the system will go into dead lock. Moreover, if some teams have to wait for a very long period, the performance of collaborative work is also degraded. Design services thus need to implement the management of design models to support synchronous operations. This piece of work may also be needed by whichever of the other services (e.g. collaborative simulation) that involves synchronous operations on system models and information objects.

8.4.3 Information and Knowledge Management

As discussion in Sect. 8.3.3, information services are very important for CPD and appear in many stages of the design process whilst knowledge services are also necessary for some key stages. In complex design projects, designers need a large amount of information to generate ideas, evaluate solutions, and make decisions. This is more prominent in the context of CPD in which these tasks are often carried out by several teams. Engineering designers actually have various knowledge needs and the supply of relevant knowledge is very helpful [45]. Information and knowledge management is thus of significant importance for DBS. To make informed decisions, designers need to obtain information about market needs, project management, manufacturing resources, and environmental impacts. In the service-oriented architecture, information services need to support the capture of both structured and unstructured information and supply the captured information to team members based on their context of working. Moreover, the sharing of information should be limited to the extent that confidential information of any individual team is kept safe. The issues discussed above can all determine the implementation of information services.

Similarly, knowledge should be shared ‘cautiously’ as well because it is perceived as a kind of intellectual property and largely determines the competitive strength of an organization. Knowledge services need to deal with the licensing of knowledge access as well as to support the capture and store of knowledge as design projects proceed. It is a key issue that the capture of knowledge should not obstruct the work of designers and project managers and as such, it is also necessary to develop effective knowledge capture methods. In CPD, design tasks are carried by several distributed teams that have different methods for knowledge management, which makes the capture of knowledge even more difficult. In addition to the capture and storage of knowledge, its subsequent retrieval and re-use is also a critical issue which has not been well addressed [46]. In the context of distributed CPD, the retrieval of knowledge becomes more complicated as knowledge records may be stored in different places and the knowledge needs of different team members can be diverse. These issues need to be well addressed by the knowledge services.

8.4.4 Information Retrieval and Semantic Technology

As discussed in the last section, the subsequent retrieval and re-use of design knowledge is a critical issue. Actually, various retrieval methods need to be developed for the proposed DBS paradigm which concerns information in various forms. For example, design knowledge is generally captured in a structured way and as such its retrieval methods can exploit the inherent structure to improve retrieval performance [46]. Simulation technology is widely used in complex product development and the number of simulation models is large in CPD. Retrieval methods are required for these models to support engineers to find models as per specific needs such as function, discipline, and performance. Information retrieval is a popular area of research and has developed rapidly in recent years due to the emergence of commercial searching engines. Many methods have been developed, e.g. keyword-based search, language models, and machine learning techniques [47]. Apart from the technologies and methods mentioned above, the information seeking behaviours of designers should also be taken into account in the development of effective retrieval methods [48].

The development of retrieval methods depends on the specific structure, format and content of information as well as the information needs of engineers. These issues all need to be considered in practice. There are two promising areas of research for the retrieval of design information. The first is raised by the fact that design engineers often cannot express their needs explicitly and re-phrasing is common in face-to-face knowledge acquisition. Therefore, it is useful to develop a system which can ‘chat’ to designers like an experienced colleague to clarify information needs, and as such supply more relevant information. The second area is Semantic technology which is not only promising in information retrieval but can also help improve the effectiveness of system integration. In this section, only its potential use in design information retrieval is discussed. With the support of Semantic technology, retrieval methods can better understand design engineers’ queries whilst being ‘aware’ of the contents of information. Thus improved retrieval performance can be achieved and intelligent assistance can be offered to designers. A lot of work can be done in this area as information records accumulate.

8.4.5 Multidisciplinary Collaborative Simulation

Multidisciplinary Collaborative Simulation (MCS) is an important technology for both CPD and Virtual Prototyping (VP), aiming at evaluating the performance of design solutions at the system level and using a digital scheme. MCS achieves rapid development in recent years ascribed to the wide application of CAE tools, with an emphasis on the synergic collaboration of multidisciplinary computational models at simulation run-time. There are mainly two methods for MCS: a centralized method and a distributed method. The former is generally implemented based on the programming interfaces between simulation tools and selects one of the models as the central model that communicates with others at run-time using the interfaces. The distributed method emphasizes a more general framework in which an external programme is used to communicate with all the models. As well as being flexible and scalable, the distributed method also has advantages of supporting model integration in a distributed environment (i.e. good accessibility) and enabling cautious sharing of information. A manifest drawback of the centralized method is that it is only applicable to the cases where the simulations tools involved have interfaces between each other. The challenges for the distributed method include the modeling of complex systems, the run-time assembly between computational models with different integration methods, the ‘cautious’ sharing of simulation data, and the effectiveness and efficiency of data transfer in a distributed environment. Simulation services are an important part of the service-oriented architecture and therefore should be included by any design system for DBS. The use of virtual simulation can greatly improve effectiveness and efficiency of system evaluation and reduce evaluation costs in terms of both money and time. The challenges are also prominent, e.g. how to improve simulation performance in terms of accuracy, speed of running, and reliability. So far, successful applications of MCS to design problems are not many, and thus the development of effective MCS systems and the improvement of performance are promising areas for further work.

Apart from the enabling technologies discussed above, there are also other interesting and important topics, e.g. the development of straightforward interfaces for design engineers and the accessing of design system from mobile devices. Moreover, seamless integration between design and other life-cycle issues, such as service, disposal, and inventory analysis, also deserves further work. These issues can all be taken into account in the implementation of a DBS system on the basis of its specific requirements.

8.5 Service Oriented Collaborative Simulation

A DBS paradigm and its enabling technologies have been discussed in the last two sections. Such a paradigm can support the complex CPD process by developing a modular and flexible architecture. Tasks requiring great expertise, such as model creation, system integration, information/knowledge management, multidisciplinary simulation, and system evaluation, are all carried out by assessing relevant services supplied by specialized teams. In this way, designers and project managers, as users of a design system, can work in a virtual environment to complete design tasks by assessing and integrating services without the need of fully understanding the technical details. The integrated use of services is flexible and facilitates the re-use of both infrastructure and expertise. The implementation of this paradigm is actually complicated and depends upon lots of technologies, raising the need for understanding the requirements and methodologies for developing design systems. In this section, the design and implementation of a service-oriented collaborative simulation system is described as a case study for developing design systems for DBS.

8.5.1 System Analysis and Design

Multidisciplinary collaborative simulation is a central part of DBS as it is aimed at supporting the collaborative development of simulation models and the running of simulation for evaluating design solutions at the system level. In collaborative simulation, several teams work at different locations to create models, establish communications, run simulations, and analyze results obtained from simulations. It is a typical case of CPD albeit it does not cover all components of the architecture discussed in Sect. 8.3.2. Firstly, it involves all the four issues of CPD, namely, information, collaboration, integration, and computation. Secondly, it also requires a flexible system framework and involves various functions to be provided as services. Thirdly, it needs to be supported by distributed computing technologies. Therefore, the issues considered in its design are similar to those involved in DBS.

Computation is the core of multidisciplinary collaborative simulation as simulation models run in parallel and exchange data to complete complex simulation tasks. Hence, simulation models need to be provided as services which can effectively handle data exchange during run-time and hide technical details by providing only functional interfaces. Information services are also important as they can supply useful information about both the simulation problem and the simulation process. Moreover, engineers should be able to access simulation data to identify problems and develop improved solutions. The use of simulation is aimed at evaluating performance of proposed solutions and therefore the accuracy of simulation is not only determined by numerical algorithms but also largely depends on the accurate transfer of design data, making the function of integration services prominent. Collaboration is an important feature of collaborative simulation as it is needed for many different stages such as problem formulation, system analysis, model creation, simulation running, and decision-making. Simulation models are often created based on CAD models and as such the discussion on data exchange in Sect. 8.4.2 is still applicable and the requirement for synchronous operation on system models is still demanded. Collaborative simulation also requires distributed computing technology whilst having a focus on the accuracy of data transfer in terms of both time order and variable value. In summary, a flexible service-oriented solution is required for collaborative simulation.

8.5.2 A System Framework for Multidisciplinary Collaborative Simulation

A model-centric framework for multidisciplinary collaborative simulation system is proposed by the authors, as shown in Fig. 8.3. This simulation-based design approach is specifically applied for the transition between conceptual design and embodiment generation. At this stage, many decisions need to be made and simulation can be used to provide important information about the performance of proposed solutions. The framework consists of three main tiers, namely application tier, platform tier, and infrastructure tier. Application tier is on the top and consists of the functions that a software system should provide for product development. There are three core components for the system, namely multidisciplinary simulation, multidisciplinary optimization and Product Data Management (PDM). Simulation is carried out in an integrated modeling and simulation environment and simulation results are transferred to an optimization engine in real-time. Optimized variables are then sent back to the simulation environment to execute the next step of simulation. The models and data after simulation and optimization are managed in the PDM system for further usage.

The platform tier comprises the enabling tools for system modeling, simulation, analysis and optimization. Domain models in product design are generally

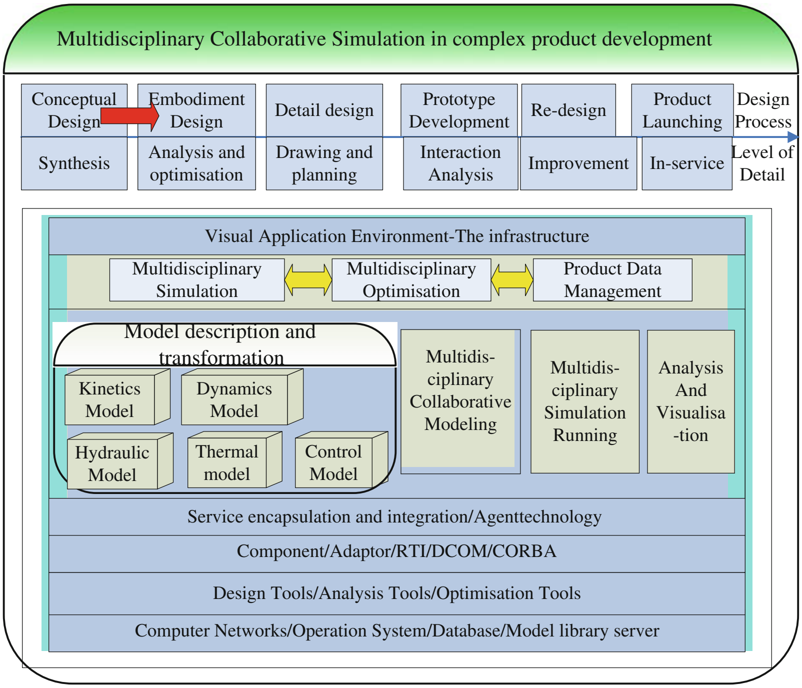

Fig. 8.3 A framework for multidisciplinary collaborative simulation systems

constructed using professional CAE packages. A prerequisite for multidisciplinary collaborative simulation is that distributed models should have uniform interfaces, and thus requires the development of a mechanism for model description and transformation. The collaborative modeling tool is based on such a mechanism and aims to hide technical details about both the implementation of, and the interaction between, simulation models. At simulation run-time, a tool that can monitor and control the process of simulation is also necessary. Last but not least, tools for data analysis and visualization are also helpful to evaluate the simulation effectively and efficiently. In the infrastructure tier, various systems, platforms and tools are operating and communicating on the information infrastructure in enterprises. Disciplinary models and optimization algorithm are implemented using specific CAE tools which are usually heterogeneous and have no interfaces between each other. As a consequence, middleware technology, component technology, and software adaptors should be utilized to facilitate the access to these models. Furthermore, open standards such as Web service are helpful for supporting interoperability in a simulation involving distributed heterogeneous models. Based on these techniques, the infrastructure can facilitate the creation of disciplinary models, enable the interactions between them, and provide solutions for underpinning collaborative simulation running.

8.5.3 Prototype System Implementation

To evaluate the service-oriented solution, a prototype system has been developed. Currently, the system has functionalities of collaborative modeling, simulation running, and simple post-processing. The services implemented include information services, simulation services, and integration services. Collaboration services have also been developed to support collaborative work in a distributed virtual environment, but core functions such as synchronous operation and complex data exchange, nevertheless, have not been implemented. The distributed computing technologies used for this solution are Web Services and the High Level Architecture (HLA). The prototype system is developed as a Web-based platform which can be assessed by engineers and analysts wherever they are based to create models, run simulation, and analyze simulation results. For the sake of brevity, this book chapter mainly describes the integration of Web Services and HLA in this solution. Detailed discussion on the technologies used in this solution can be found in [41], and readers interested in more details about the system are referred to other relevant publications [7].

The combinative use of Web Services and the HLA is taken as the solution underpinning the prototype system. The solution is illustrated in Fig. 8.4 where MVMD stands for multi-view model description. Specifically, the HLA-based federation is used to support run-time data exchange, which runs in Local Area Network (LAN) to achieve improved efficiency. The simulation of individual models is executed by performing numerical integration using the solvers embedded in the commercial CAE tools which are used to create these models. To implement the distributed computation and interaction of these models, each model is encapsulated as a Web service which is accessible to remote service subscriber. This enables the simulation functionality (encapsulated as Web Services) and run-time interaction (implemented in HLA federation) to be separated

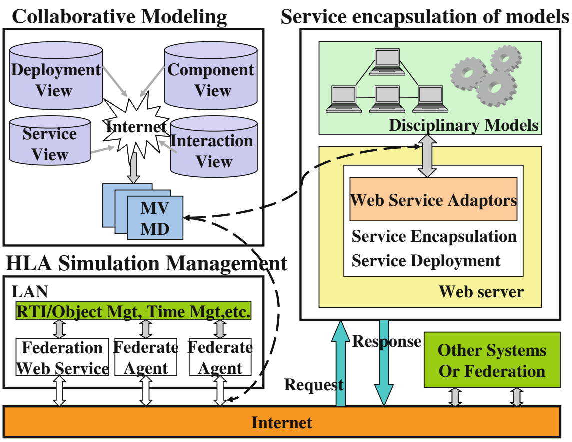

Fig. 8.4 A solution based on web services and HLA

as independent modules, which implements the flexible integration of a simulation system, i.e. changes in any module can be addressed locally. Thereby, the distributed and interactive features are all supported by the run-time integration of HLA and Web Services. Moreover, a multidisciplinary modeling paradigm is introduced to provide the users with a high-level tool for describing a simulation system. The information obtained in the multidisciplinary modeling is used to guide the construction of HLA federation and Web Services encapsulation and development. Some snapshots of the Graphical User Interfaces (GUIs) are shown in Fig. 8.5. It is noteworthy that this is still a preliminary stage of implementing a collaborative simulation platform and further work is still needed to improve the system and address performance issues.

8.5.4 The Design Process and a Simulation Example

To illustrate the performance of the prototype system, the design process of multidisciplinary simulations is analyzed and a simulation example is run on it. Figure 8.6 shows the six-stage process together with the developers and services involved at different stages.

The prototype system can assist users (design engineers, project managers, IT engineers, and system analysts) to perform tasks at these stages by providing Web-based interfaces and integrating relevant services. Specifically, the first stage is the analysis of simulation requirements, which involves the participation of design engineers, project managers, and system analysts to identify requirements for the simulation problem with the support of information services (e.g. specification, available models, and information about previous projects). The synthesis stage heavily relies on the experience and knowledge of design engineers and system analysts, and thus accessing to information/knowledge services is quite helpful. The development of simulation models is mainly completed by design engineers with the support of design services and involves two levels of modeling work. The first level is system modeling at which design engineers work together to decompose a complex system as subsystems. The subsequent subsystem modeling is the second level which involves the creation of subsystem models for different disciplines.

The subsystem models are mainly created using either commercial CAE tools or bespoke packages. IT engineers and system analysts work together to make these models assessable on the Internet at the next stage namely encapsulation of models as services. In this way, these models can be integrated at simulation run-time. Therefore, simulation and integration services are needed at this stage. Once these models are made assessable, collaborative simulation can be started which enables the collective use of simulation knowledge and computational resources. The running stage is the core of the design process and therefore involves the participation of engineers, analysts, and IT experts. The last stage is post-processing and system analysis, which involves the analysis of simulation results

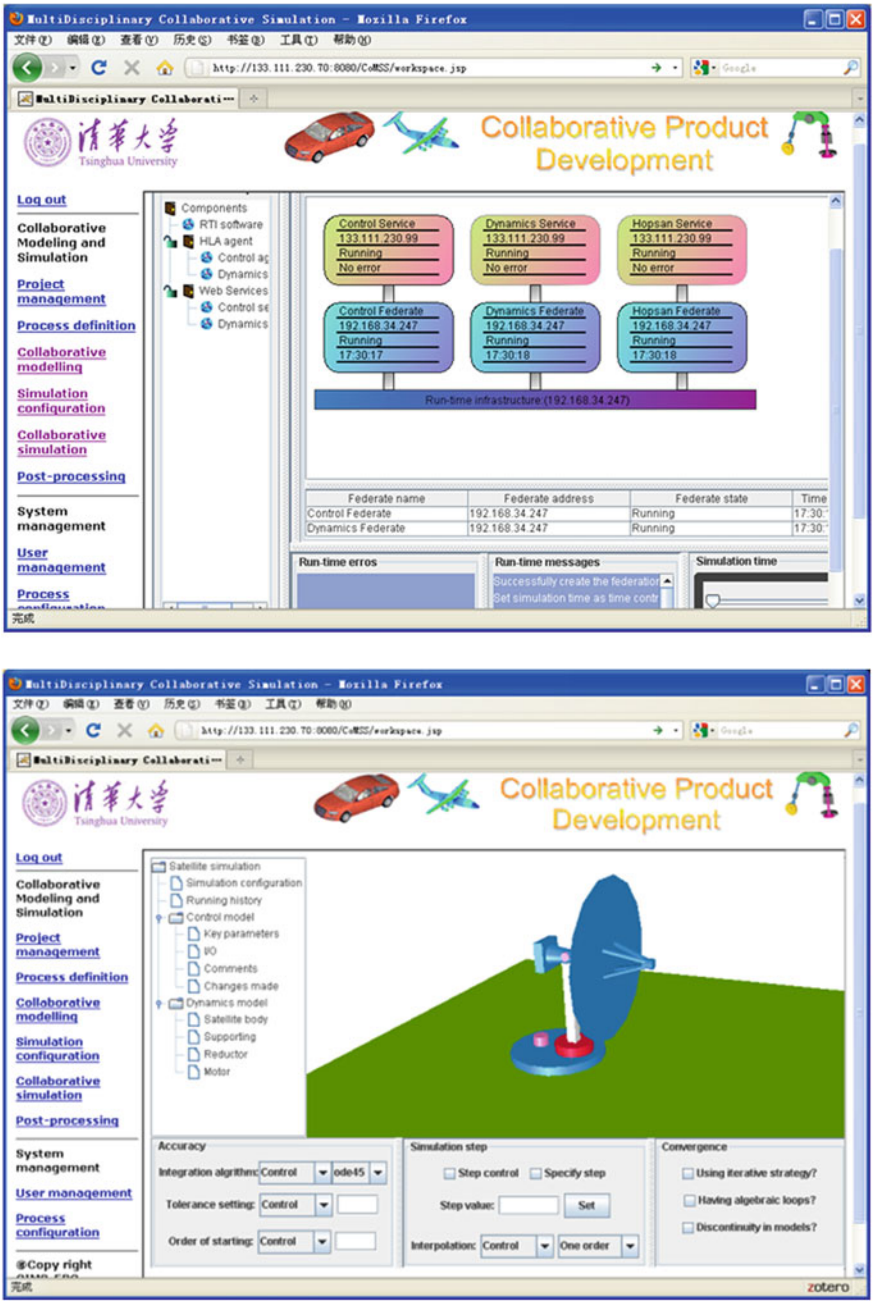

Fig. 8.5 Snapshots of the GUI of the prototype system

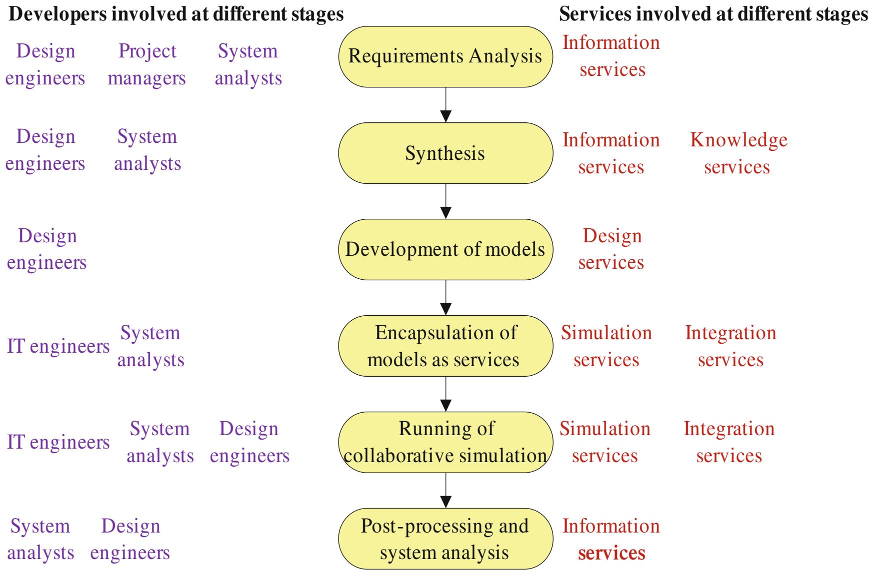

Fig. 8.6 The design process based on the prototype system

and the identification of areas for improvement and optimization. At this stage, design engineers and system analysts evaluate the performance of a design solution and record relevant information for later usage.

The simulation of the tilting process of a satellite is run on the prototype system. This example is shown in Fig. 8.5, which involves two models, namely a control model and a dynamics model. The objective of simulation is to evaluate whether the control algorithm can successfully drive the satellite body to tilt for a specified angle. Engineers work on the prototype system step by step and the developed models are encapsulated as Web services. At the running stage, users can control the simulation process and retrieve simulation results even though none of the CAE packages is installed in their computers. The current prototype can support simple post-processing and the simulation results for the satellite example are shown in Fig. 8.7. The total simulation is 0.25 s and the interval for data exchange is set as 0.005 s. This means that the simulation involves 50 data exchanges and the time taken for each exchange is about 1 s. It is noteworthy the initialization of simulation engines takes a relatively long time and in practice they should be initialized before the simulation starts. In summary, the prototype system can assist users to create models, run simulations, and undertaken system analysis by integrating specialized services. Therefore, it is possible to support design tasks using DBS. Issues (e.g. identification of services, use of computing technologies, and the integration of information and computing resources)

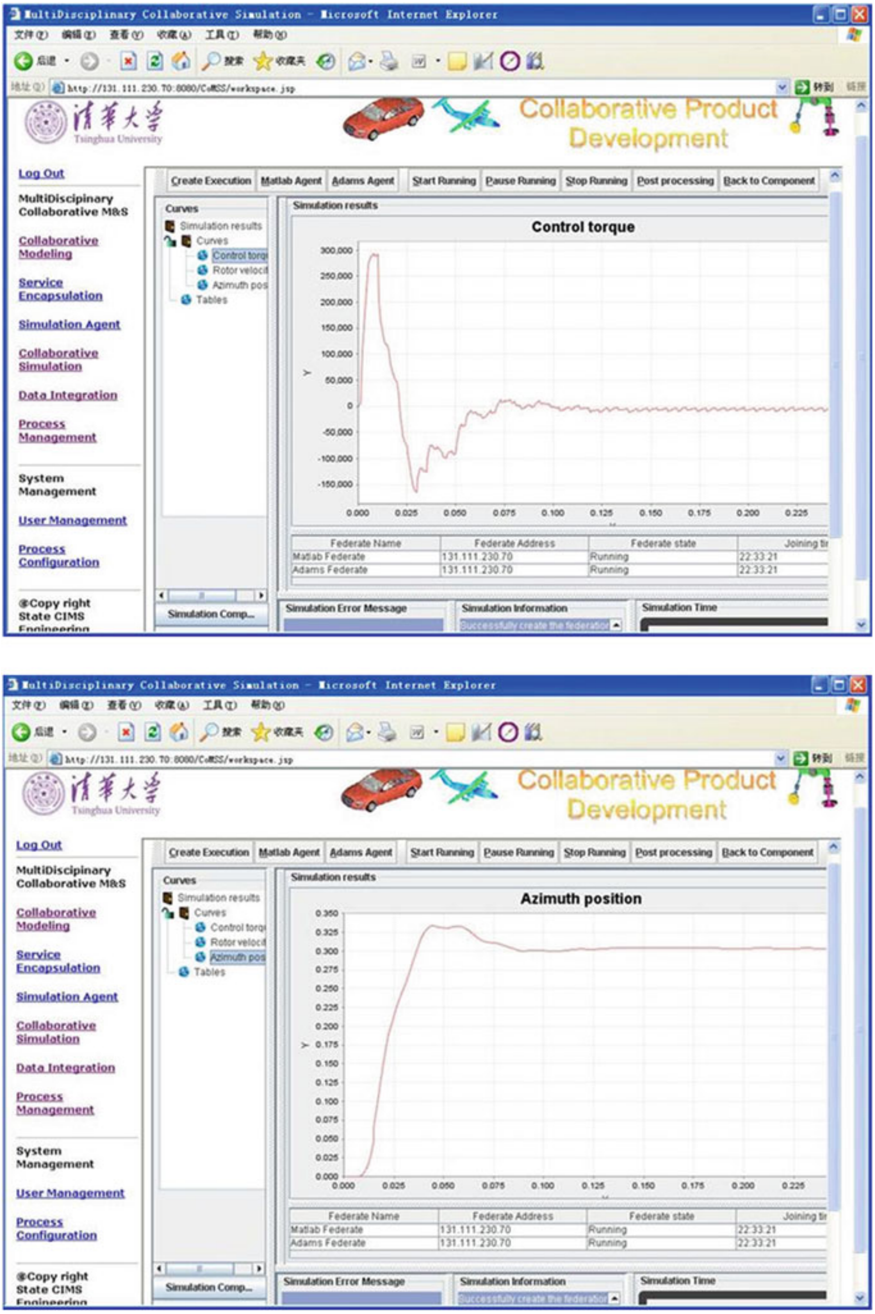

Fig. 8.7 Simulation results shown on the GUI of the prototype system

addressed in the development of this prototype can also be taken into account in the development of more powerful DBS systems. This suggests that DBS is implementable and promising for supporting complex product development.

8.6 Conclusion Remarks

This book chapter presents a new scheme for CPD, namely designing by services, which is aimed at supporting effective and flexible system integration by supplying professional, accessible, reliable, extensible, and secure services. Information, collaboration, integration, and computation are identified as the key issues for CPD, and the proposed scheme emphasizes the provision of tasks concerning these issues as services. In this way, design tasks can be underpinned by an information infrastructure which operates by accessing and integrating relevant services. This scheme has a few advantages which are difficult to achieve for traditional methods. Firstly, services are provided by teams who have the specialized information/resources and consumers of these services only need to know the service interfaces rather than the technical details. This helps achieve effective and efficient division of tasks to facilitate carrying out design projects in a collaborative way. Secondly, changes incurred in any service component can be to a large extent addressed locally as system integration is mainly done through interfaces. Thirdly, distributed collaboration is enabled with the support of modern distributed computing technologies.

Eight kinds of services have been identified in a service-oriented architecture for the proposed scheme. Their purposes together with their usage in a design scenario are described. These services are sufficient for general CPD processes and in practice they can be evaluated and selected based on specific requirements. The key enabling technologies for designing by services are identified and discussed in detail. These technologies are very important for the successful implementation of design systems for the proposed scheme. The design and implementation of a multidisciplinary collaborative simulation system is described as a case study. Preliminary work on the development of the prototype shows that the issues raised in DBS can guide the development of solutions for collaborative simulation and the use of advanced computing technologies can greatly help system implementation. DBS is a promising yet complicated topic which requires much further work. The preliminary work presented in this chapter can be used as reference models for the implementation of the next-generation distributed and collaborative engineering software applications. Our future work includes improving and evaluating the prototype system, as well as producing detailed solutions for different services in the proposed scheme.

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Chapter 9
Real-Time Work-in-Progress Management for Ubiquitous Manufacturing Environment

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Abstract Recent developments in wireless technologies have created opportunities for developing next-generation manufacturing systems (NGMS) with real-time traceability, visibility and interoperability in shop-floor planning, execution and control. This chapter proposes a referenced infrastructure of Ubiquitous Manufacturing (UM). Under this infrastructure, a Smart Gateway and a real-time work-in-progress management system (WIPMS) based on smart objects such as RFID/Auto-ID devices and web service technologies are designed to manage and control the real-time materials flow and information flow to improve the optimal planning and control of the entire shop-floor. During manufacturing execution stage, they can provide operators and supervisors with real-time status and information of current manufacturing environment. It follows a simple but effective principle: what you see is what you do and what you do is what you see. Production disturbances could thus be detected and fed back to decision makers for implementing closed-loop shop-floor control. For manufacturing information sharing and integration, a work-in-progress markup language (wipML) is used to establish the information model and schemas of WIP based on some important standards such as ISA 95 and B2MML. Then, the real-time manufacturing information can

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be effectively encapsulated, shared and exchanged between Smart Gateways, WIPA and heterogeneous enterprise information systems (EISs). Finally, the presented framework is demonstrated through a near real-life simplified shop-floor that consists of typical manufacturing objects.

Abbreviations

AMT	Advanced Manufacturing Technology
AUTOM	Manufacturing Powered by Auto-ID Technologies
AWFM	Agent-based Workflow Management
B2MML	Business-to-Manufacturing Mark-up Language
BOM	Bill of Materials
ceXML	Critical event Extensible Markup Language
EISs	Enterprise Information Systems
FMS	Flexible Manufacturing System
HF	High Frequency
ISA	Industry Standard Architecture
NGMS	Next-generation Manufacturing Systems
PRD	Pearl River Delta
RFID	Radio Frequency Identification
SOA	Service-oriented Architecture
SOMS	Smart Object Management System
SOs	Smart Objects
soUDDI	Smart objects Universal Description, Discovery and Integration
UHF	Ultra-High Frequency
UM	Ubiquitous Manufacturing
WBF	World Batch Forum
WfMC	Workflow Management Coalition
WIPA	Work-in-progress Agent
wipML	Work-in-progress Markup Language
WIPMS	Work-in-progress Management System
SQL	Standard Query Language

9.1 Introduction

Manufacturing is the battlefield of global competition. In the past ten years, typical challenges that manufacturing enterprises are facing in the dynamic global business environment are shortened products lifecycle, fluctuated demands and rapid upgrading of manufacturing technologies. To strive for their competitiveness, companies have to adapt advanced technologies and management approaches (both software and hardware). Recently, rapid developments in wireless sensors, communication and information network technologies (e.g. radio frequency identification-RFID or Auto-ID, Bluetooth, Wi-Fi, GSM, and infrared) have nurtured the emergence of Ubiquitous Manufacturing (UM) [1, 2] as core Advanced Manufacturing Technology (AMT) in next-generation manufacturing systems (NGMS). A UM system is based on wireless sensor network that facilitates the automatic collection and real-time processing of field data in manufacturing processes. In this way, the error-prone, tedious manual data collection activities are reduced or even eliminated [3].

UM provides a networked manufacturing environment free from excessive and difficult wiring efforts in manufacturing workshops [4]. In UM, real-time visibility and interoperability have been considered core characteristics [5] that close the loop of production planning and control for adaptive decision making. A new paradigm, called UbiDM: Design and Manufacture via Ubiquitous Computing Technology [6], has been proposed for the design and manufacturing of a product by using ubiquitous computing technology. The importance of the UM has also been widely identified for strategic research and development in industrialized European Union, North Americas, and Japan where manufacturing is widely considered as one of the major means of creating the national wealth.

Despite significant progress achieved by research and practitioner communities, major challenges still exist in applying Auto-ID/RFID technologies to the real-life manufacturing shop floors. For example, in a real-life shop floor, different types of Auto-ID devices may be needed due to different production requirements and working conditions. Usually, staff members usually use High Frequency (HF) tags, single items of materials are attached with bar-codes by their supplies, while pallets are often attached with Ultra-High Frequency (UHF) tags because they are cheaper and could be reused, etc. Because different Auto-ID devices entail different software drivers and invoking standards/protocols provided by their suppliers, as a result, it is both labor and skill intensive to set up and manage heterogeneous RFID devices for different industrial applications without a standardized model. Moreover, operation changes resulted from order changes is a commonplace in real-life manufacturing shop floors. Therefore, an easy-to-use configuration mechanism is necessary for defining the data capturing activities required by different manufacturing companies. Our recent investigation within several manufacturing enterprises in Pearl River Delta (PRD) of China has revealed several research questions before a breakthrough can be achieved in real-time UM. They are summarized as follows:

1. How to build up a platform to integrate and manage multiple types of Auto-ID devices to capture complex real-time information from manufacturing execution?

2. How to use a standard model to wrap the multiple types of RFID devices so that they can work in a "plug and play" manner and be used without specialist knowledge?

3. How to rapidly and flexibly define the flow of real-time data collection, which is the allocation (e.g. sequences and times) of appropriate RFID devices/ Agents to collect data from a dynamically changed production process?

4. How to facilitate the real-time WIP management through smart objects enabled UM infrastructure under the service-oriented architecture?

5. How to share and transmit the static and dynamic shop-floor manufacturing information among heterogeneous systems by using the standard services?

6. How to apply the current manufacturing standards to Work-in-progress Management System (WIPMS) so that it can be easily integrated with other EISs?

7. How to design and develop the visibility explorers based on the timely shop-floor information for different users to enhance their productivity and efficiency?

In order to address the above questions, in this chapter, a referenced UM infrastructure, the overall architectures of Smart Gateway and WIPMS, and their core technologies are described based on some advanced technologies and standard such as RFID, agents, web service, the ISA 95 and B2MML standard. It aims to eliminate the information gap between shop floor management system and representative execution units, and provide a new paradigm for the development of RFID-enabled UM solutions and corresponding WIP management. It is stated that the overall infrastructure and corresponding core technologies of this chapter have used and integrated the relevant research contributions of our previous works reported in a series of international journal papers [2, 7, 8].

The rest of the chapter is organized as follows. Section 2 reviews the literature related to this research. Section 3 outlines an overall infrastructure of smart objects enabled real-time ubiquitous manufacturing. Section 4 describes the overall architecture and core technologies of Smart Gateway. Section 5 discusses the overall architecture and core technologies of WIPMS in shop floor environment. Section 6 reports a case study on the implementation of the proposed WIPM framework for a typical manufacturing shop floor. Conclusions and future works are given in Sect. 7.

9.2 Literature Review

At least four streams of related works are relevant to this research. They are real-time manufacturing capturing, agent technologies, workflow management, as well as manufacturing information sharing and integration.

1. Real-time manufacturing capturing

Auto-ID technologies such as RFID have been widely applied to automatically capture real-time data [9]. Early RFID manufacturing applications have been briefly quoted by Brewer et al. [10]. Johnson [11] presents a RFID application in a car production line. Chappell et al. [12] provide a general overview on how Auto ID technology can be applied in manufacturing. Huang et al. [13] have implemented RFID technologies to capture the real-time information of workers, machines and materials of fixed-position and assembly line. Zhang et al. [14] have designed and developed a RFID-based smart Kanban system for shop-floor WIP management. Alejandro et al. [15] have developed an innovative and ecological packaging and transport unit called MT for the grocery supply chain based on active RFID tags.

2. Agent technology

In order to enhance the flexibility of shop-floor management, agent technology has been introduced in manufacturing applications. Krothapalli [16] proposes an agent based concurrent design environment to integrate design, manufacturing and shop-floor control activities. By combining RFID with intelligent agents, a location-sensing system [17] and an intelligent guided view system [18] have been developed. Jia et al. [19] proposed an architecture where many facilitator agents coordinate the activities of manufacturing resources in a parallel manner. Jiao et al. [20] applied the Multi-Agent System (MAS) paradigm for collaborative negotiation in a global manufacturing supply chain network. Besides, in various kinds of applications such as distributed resource allocation [21], online task coordination [22], supply chain negotiation [23], the agent-based approach has played an important role to achieve outstanding performance with agility.

3. Workflow management

Workflow management is a diverse and rich technology which has been applied in ever increasing industries. Hollingsworth [24] defines that a workflow process is a coordinated (parallel and/or serial) set of process activities that are connected in order to achieve a common business goal. Lazcano et al. [25] use workflow technology to manage complex processes in e-commerce and virtual enterprises. Montaldo [26] applies workflow management system to enhance business performance for small-medium enterprise. Tan et al. [27] adopts a novel dynamic workflow model-based fragmentation algorithm to execute the distributed processes. Lin et al. [28] propose a compound workflow model (CWM) is to provide graphic presentation of the production process. Zhang et al. [29] establish a distributed workflow management model to define, configure and execute the different manufacturing processes.

4. Manufacturing information sharing and integration

In real-life manufacturing environment, different enterprises usually use the different software packages. Difficulties of information integration may arise when information is exchanged among heterogeneous application systems. Therefore, standard models and schemas of manufacturing information play important roles in information sharing and integration of heterogeneous enterprise applications, not only at business or at manufacturing levels but also inside a single enterprise or between networked enterprises. Siemens Energy & Automation, Inc. [30] has developed an interface to achieve seamless connections between ERP and process control systems. Standard ISA95 [31] has been developed to provide standard models and terminology for the design and operation of batch control systems. Today, the availability of Web-based XML communications successfully bridges the gaps between heterogeneous EISs. Business-to-Manufacturing Mark-up Language (B2MML) [32] standard developed by World Batch Forum (WBF) specifies accepted definitions and data formats for information exchange between different EISs.

9.3 Overview of Real-Time Ubiquitous Manufacturing

This section presents a conceptual infrastructure for ubiquitous AUTOM (Manufacturing Powered by Auto-ID Technologies), as summarized in Fig. 9.1. It helps defining vertical and lateral manufacturing visibility and interoperability.

The aim of the proposed UM infrastructure is to apply Auto-ID technologies and develop an easy-to-deploy and simple-to-use real-time information infrastructure for manufacturing enterprises to achieve seamless dual-way connectivity and interoperability between heterogeneous EISs, shop floor and production line/ workstations. According to the manufacturing hierarchy, the proposed real-time UM infrastructure includes three core components, namely smart objects, gateway and shop-floor management.

Smart Objects (SOs) are physical manufacturing resources that are made "smart" by equipping them with Auto-ID devices (i.e., RFID devices). Fox example, those with RFID readers are called active SOs (e.g. work stations and forklifts) while those with RFID tags are called passive SOs (e.g., tagged materials, pallets etc.). SOs interact with each other or Smart Gateway via wired and/or wireless connections and thus create an intelligent ambience in shop floor.

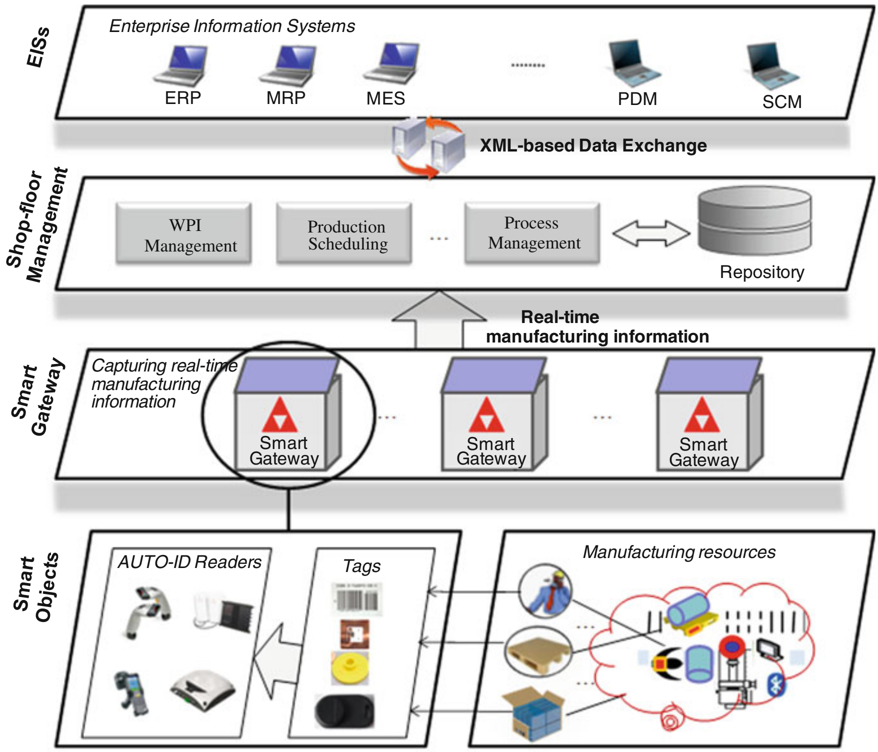

Fig. 9.1 A referenced infrastructure for ubiquitous manufacturing

In addition, taking advantages of its corresponding intelligent agent, SOs possess specified logics, processing ability and thus are able to sense, reason, and interact in the intelligent ambience.

Smart Gateway acts as a server to host and connect all SOs of the concerned production line or work-cell or work station, and also provides a suite of software applications (Agents and AWFM: Agents Based Workflow Management Framework) for managing their operations and activities. Smart Gateway captures real-time manufacturing information and passes it to upper-level applications or information systems according to a predefined workflow to enable appropriate real-time manufacturing process. From software perspective, a Smart Gateway is essentially an agent-based smart object management system (SOMS) [7] which defines, configures and executes the corresponding agents of SOs through services tools. From the hardware perspective, a Smart Gateway is like a hardware hub, which allows different type of connections (i.e. Bluetooth, TCP/IP, and USB etc.) to connect various types of SOs.

Shop-floor Management is at the center of the overall infrastructure. Its purpose is to provide a two-way information channel between shop floor and enterprise applications. From operations to enterprise decisions, it collects real-time information (e.g. real-time work-in-progress information) from the associated Smart Gateways and converts the information into standard formats to be directly used by enterprise information systems (EISs). From decisions to operations, on the other hand, it can receive enterprise's decisions, such as production planning and scheduling, from EISs and translate them into production orders or tasks that can be readily used by shop-floor operators or devices. A series of modules such as WIP management, production scheduling, internal logistics scheduling, process management, performance analysis etc. are developed and integrated in shop-floor management to provide service tools for real-time information exchanging between EISs and Smart Gateways.

In this chapter, the overall architecture and core technologies of the Smart Gateway and real-time WIPMS in a ubiquitous manufacturing environment will be described.

9.4 Smart Gateway

9.4.1 Architecture of Smart Gateway

Smart Gateway is an innovative platform that centrally connects and manages the multiple types of SOs necessary for capturing real-time manufacturing data. It has two unique characteristics. The first is "Plug and Play" scalability. SOs can be plugged in or removed from the Smart Gateway without stopping their functions for reconfiguration. The second is "reconfigurable", which means SOs can be easily configured for different processes with different real-time information capturing requirements.

The overall architecture of Smart Gateway can be seen in Fig. 9.2. It consists of three main components, namely smart objects and wrapping agents, smart object UDDI, Agent-based workflow management and real-time visibility explorer.

1. Smart objects and wrapping agents

For better managing the heterogeneous SOs, agent technologies are used to wrap different SOs as standard web services using the uniform service-oriented architecture (SOA) so that SOs are deployed in a "Plug and Play" fashion at Smart Gateway. It is otherwise very complex to configure various SOs with different communication interfaces in real-life manufacturing environment (e.g. HF reader, UHF reader, etc.).

2. smart objects Universal Description, Discovery and Integration (soUDDI)

It serves as a platform-independent framework for describing and discovering the services of smart object agents over the Internet. On the one hand, it can be used to register and publish standard web services of agents [33]. On the other hand, the real-time manufacturing applications can be implemented through binding and invoking the real-time data capturing services of the relevant agents in soUDDI.

3. Agent-based workflow management

Different products are manufactured with different production processes. Accordingly, same smart objects may play different roles in different production processes. In order to facilitate the configuration of smart objects in different manufacturing processes, a workflow management mechanism is considered as a core technology in Smart Gateway to define, configure and execute different processes.

9.4.2 Core Technologies of Smart Gateway

9.4.2.1 Service-Oriented Agent

Agent concept is adopted for wrapping all types of smart objects connected to the Smart Gateway as "plug and play" objects. The agent is smart because it can perceive the dynamic changes of manufacturing environment and reflect the

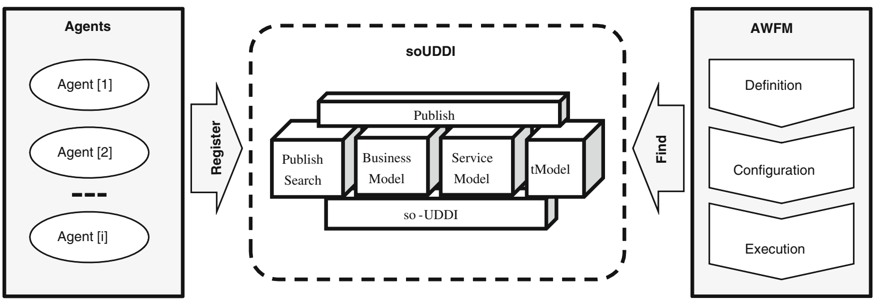

Fig. 9.2 Architecture of agent-based smart gateway

changes to Smart Gateway. For example, when an operator with a card (HF Tag) comes to one workstation that placed a Smart Gateway, the corresponding agent of a HF reader can capture the data of the operator card and translate it into meaningful manufacturing information. Then, the agent knows which operator has arrived at which workstation at which time etc. and navigation will be given based on the rules adopted. To fulfill this purpose, the agent should consist of the following four main modules.

1. Definition and Auto-Driven Module

It is used to wrap various drivers of heterogeneous SOs to form a driver library which enables the newly plugged SO to be "Plug and Play" in a Smart Gateway with only simple definition of some basic parameters. Two driven modes, standard interface driven and the third-part driven, are designed in this module.

2. Reasoning Model

It is designed to enhance the intelligence of the agent. Rule-based methods are adopted to accelerate agent to make decision based on real-time manufacturing environment and production logics. The fundamental element of a rule is function. A function has a name, a set of arguments, and a return value. Function itself can be an argument of another function.

3. Services Module

It is responsible for wrapping agents into standard web services so that they can be easily invoked through internet. Three types of services, namely "Reading/Writing service", "data processing service" and "input/output service", are involved in this module.

4. Communication Module

It is used to implement information exchanging between SO, agent and Smart Gateway. The communication between SO and agent can be achieved by auto-driven strategy, while the communication between "agent to agent" and "agent to Smart Gateway" both adopt SOA.

9.4.3 soUDDI

As discussed above, agents are exposed as web services from Smart Gateway. A soUDDI platform is developed to manage these services so that they can be easily found and invoked for implementing real-time manufacturing.

Figure 9.3 shows the architecture of soUDDI, which is a platform-independent, XML-based registry for the agents' services. As seen in the middle of Fig. 9.3, the services of agents are published to soUDDI and thereafter invoked by the service requestors to conduct real-time manufacturing activities. A complete process of using soUDDI involves three main phases. In the first phase, the distributed services of agents are registered and published at soUDDI, as indicated by "(1) Publish". During the publishing process, detailed information of each service of an agent, such as its location, capability as well as the interfacial description will be provided. Then, the published services of agents can be searched according to the real-time

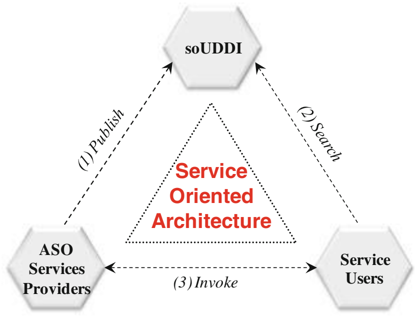

Fig. 9.3 The architecture of soUDDI

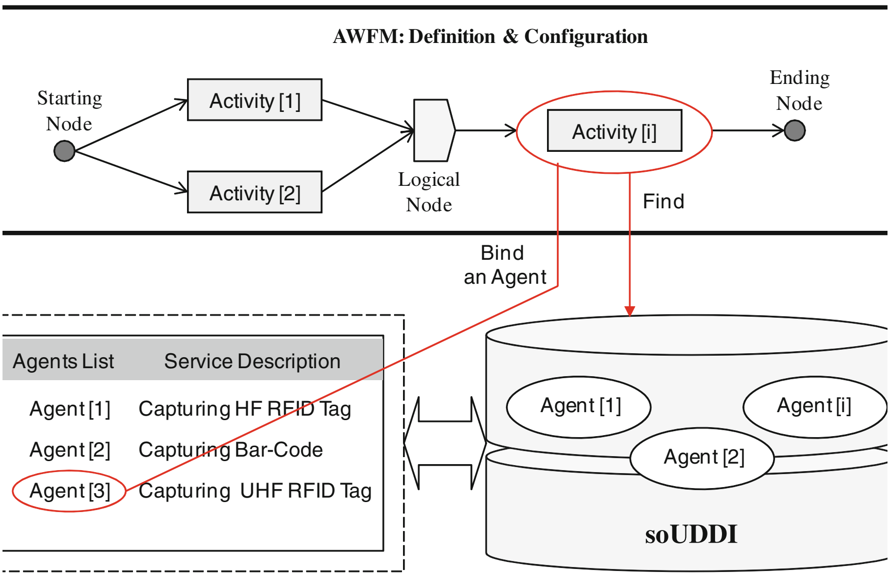

Fig. 9.4 Agent-based workflow management model

requirements from soUDDI, as indicated by "(2) Search". The third systems can bind the selected services and invoke them, as indicated by "(3) Invoke". During the execution phase, the users or other systems could invoke the corresponding services of agents to capture the real-time manufacturing information.

9.4.4 Agent-Based Workflow Management

Figure 9.4 shows the AWFM framework. Specifically, the topology of activities involved in the manufacturing process and its corresponding data capturing workflows will be defined in this AWFM model first. Then, specific agents (smart objects) will be chosen for the execution of each activity from soUDDI based on their published capabilities. In the actual execution stage, AWFM will coordinate the data collection and transformation activities based on a defined set of rules and knowledge.

There are three basic elements in AWFM: activities, business logic, and agents (participants). Activities are specific tasks in a process while business logic indicates how activities are performed and under what trigger conditions. Agents (Participants) represent the operators who will fulfil the tasks of activities.

Referring to Workflow Management Coalition (WfMC), an industry-wide consortium of workflow system venders, the implementation of AWFM consists of two core components, namely designer and executor. A workflow designer is a graphical interface application enabling shop-floor managers to configure or reconfigure the flow of data collection without using any programming languages. A workflow executor is responsible for instantiating workflows and the associated agents to perform the defined activities.

9.5 Real-Time WIP Management System

9.5.1 Overall Architecture

It is well-known that work-in-progress management system plays a critical role in manufacturing system. It controls the material and information flows, monitors the WIP level for each workstation/stock, tracks the statuses of each manufacturing object and the progress of each production order, and also responds to requests from the shop floor [34, 35]. In a UM framework, WIPMS facilities of shop floor are required to implement real-time traceability, visibility and interoperability in improving the performance of shop-floor planning, execution and control [8].

Figure 9.5 shows the overall information architecture of WIPMS. It acts as a sandwich and plays an important role to manage and control the material and information flows in the entire shop floor. Following this architecture, the users or other systems can get or update the real-time WIP information by easily sending a request to WIPA. Four main components are involved in the designed WIPMS, namely (1) Data Source Service, (2) WIPA: Work-in-progress Agent, (3) Gateway Data Service, and (4) Registry and Repository.

Data source service provides data acquisition, processing and updating services for sharing and integrating information between WIPA and EISs. WIPA is responsible for dynamically forming the WIP information instance in terms of the specific production process, as well as establishing the binding relationship between WIPA and relevant Gateways. Gateway data service provides standard methods for WIPA to get or update real-time manufacturing information from or to corresponding gateways. Registry stores all the offline data for definition and configuration stages, e.g. definition of gateway, wipML schema, instances and configuration

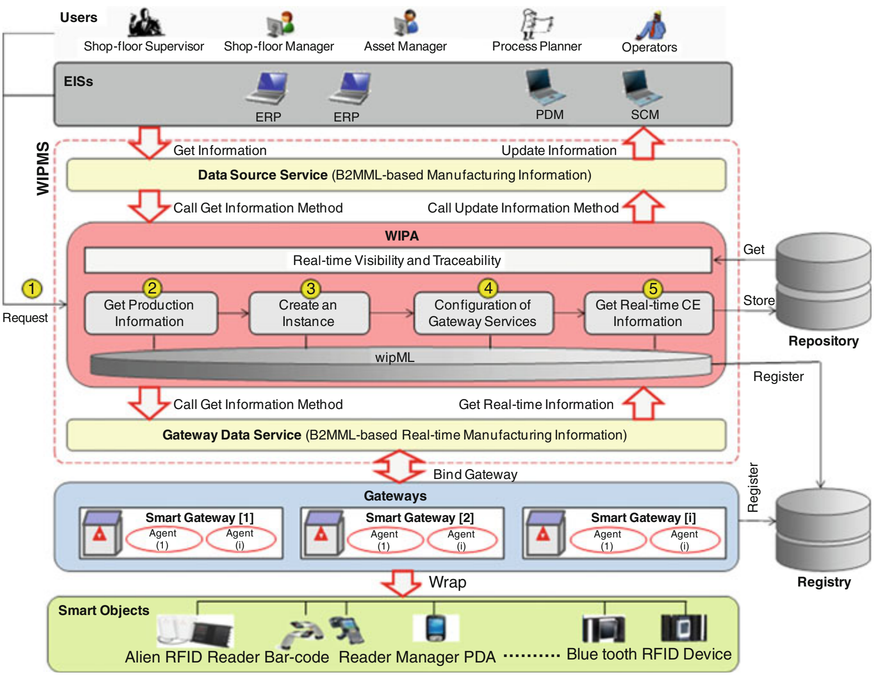

Fig. 9.5 Overall architecture of real-time WIP management system [8]

information between WIPA and gateways. Repository stores the extracted information from EISs schemas and the online data captured by distributed gateways during manufacturing execution.

9.5.2 Working Logic of WIPMS

A procedure of using the WIPM for different users or systems can be also seen in the middle of Fig. 9.5.

At the beginning, the users or systems submit their request to WIPA. For example, the request can be a real-time progress of a production order. Then, the WIPA will invoke the data source service to get the necessary information relevant to the production order such as the product BOM, schedule information etc. from the up-level EISs. Based on the gotten manufacturing information and the information schema (wipML) of WIPA, a new WIPA instance is created, which includes the manufacturing BOM information. For each node of the manufacturing BOM, its dynamic information nodes can be captured by the gateway data service. And the binding model is used to build up the bind relationship between the dynamic information nodes and the corresponding gateways. During execution, the huge manufacturing information captured by each gateway will be processed by critical event model according to the user's request. Finally, the result of the request will be either returned to users by visible explorers or updated to the corresponding EISs by data source service. Here, the visible explorers provide graphic user interfaces for effectively managing and controlling the material and information flows in the entire shop floor.

9.5.3 Core Technologies of WIPMS

9.5.3.1 Data Source Service

The objective of data source service is to build up a bridge for information communication between WIPA and heterogeneous EISs. Due to the difficulties of information sharing and integration among heterogeneous EISs, B2MML standards are adopted in this component to provide standard schemas for manufacturing elements. The inputs of this component are the parameters of the data source of the EISs which users want to acquire or update information from or to, while the outputs are the standard information based on B2MML schemas.

Three main modules are involved in this component. The first is definition of data source module. It is responsible for defining and creating configuration file for describing the information of various data source of different EISs. The result of this module is an XML-based definition file which consists of multiple data source nodes, which records the main parameters, attributes (e.g., data source, data connection driven, data structure etc.) and Standard Query Language (SQL) statements for the corresponding database. The second is data transmitting service module. It provides standard methods such as Get_Data_Method() and Update_Data_Method() for users or systems to attain or update information they needed from or to various EISs. It adopts web service architecture and the input parameters of each method are defined as standard XML segment. The third is data processing module. It is used to process the isolated and inconsistent manufacturing data in shop floor as standard information schema. Ten types of B2MML schemas such as personnel, material, equipment, maintenance, production capability, process segment etc. are adopted in this module for describe the information of man, machine, material and production process etc.

9.5.3.2 Gateway Data Service

The objective of gateway data service is to establish an information exchange channel between WIPA and various Smart Gateways. Following service oriented architecture, the reading and writing functions of Smart Gateway can be encapsulated as web services that can be easily published, searched and invoked through internet. WIPA can easily call them through gateway data service to get or update the real-time information without considering which types of smart objects are installed at the gateways.

The outputs of this component include (1) the real-time manufacturing information at gateways that exposes as standard B2MML schemas; (2) the updated manufacturing information at gateways. Similar to data source service, this component also has three main modules. Definition module is responsible for defining and creating configuration file for describing the information of various gateways. For example, gatewayID is a unique ID to each physically deployed gateway. Manufacturing resource ID indicates that the gateway is used to capture the real-time information occurred at the corresponding manufacturing resource. Data transmitting service module provides standard methods such as Write_Data_Method() and Read_Data_Method() for WIPA to get or update real-time manufacturing information they needed from or to distributed gateways. Data processing module is used to process the real-time manufacturing data captured by gateways as standard information schema. To make the manufacturing data more meaningful and be easy to understand by other systems, B2MML schemas are also adopted to convert the real-time data to uniform manufacturing information.

9.5.4 WIPA: Work-in-progress Agent

WIPA acts as a core component in WIPM framework. On the one hand, it is also responsible for establishing WIP instance by extracting the necessary information or updating changed information from or to heterogeneous EISs through data source service. On the other hand, it is also responsible for configuring the distributed Gateways according to specific logical relationship to get real-time information of WIP in the entire shop floor.

The structure of WIPA is described in Fig. 9.6. Its inputs are the information of BOM, scheduler, CAPP and real-time information captured by relevant Smart Gateways. Its outputs are the real-time information related to products produced, materials consumed, exceptions etc. of individual manufacturing resource and the overall real-time production progress, materials flow and production disturbances etc. of the entire shop floor. Three models are included in WIPA. They are information model, binding model and critical event model.

1. Information Model (wipML)

It is used to build up an information structure of WIPA, which consists of seven basic B2MML schemas such as production, person, equipment, material, process segment, product etc. as seen in Fig. 9.7. This information model is consistent with the manufacturing shop-floor hierarchy that is a manufacturing shop floor hosts one or more production lines/work-cells. Each production line or workstation is involved of a variety of manufacturing objects such as persons, equipments; materials etc. and different production lines are often designed to enable different production processes.

To describe the information model of WIPA, a wipML schema is developed which contains and extends the set of B2MML standards in a pragmatic and innovative manner for the definition and operation (e.g. messages) relevant to

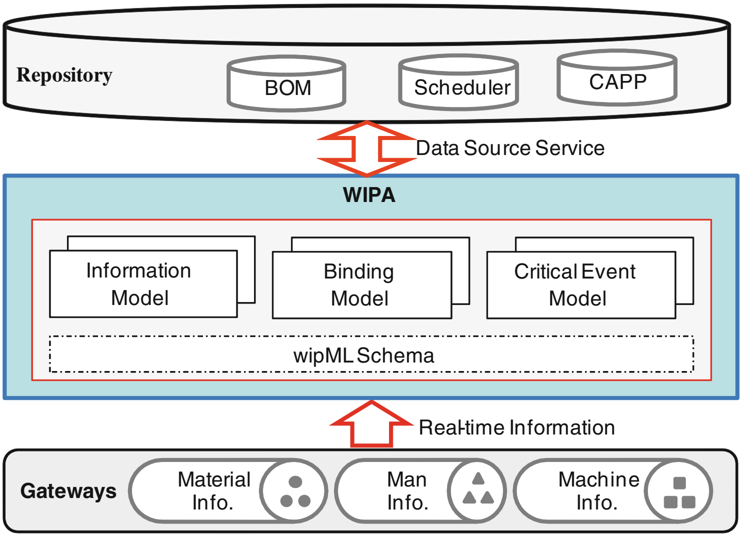

Fig. 9.6 Structure of WIPA [8]

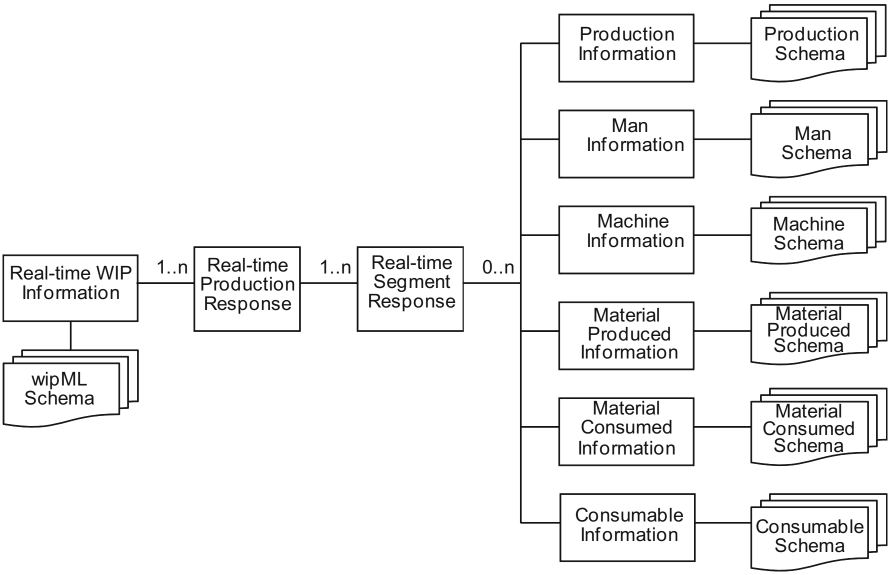

Fig. 9.7 Information model of WIPA

WIP. For each wipML instance, it stores the information such as product BOM, production order, production scheduler, production process etc., as well as the input/output relationships between WIPA and gateways. Following wipML schema and gateway data service, the Smart Gateways know where the captured real-time manufacturing information should be sent to.

2. Binding Model

Generally, different manufacturing shop floors may probably have different production processes. Even if in the same shop floor, different products also have different production process.

To effectively address these problems faced in real-life manufacturing environment, a flexible and configurable binding model between WIPA and Smart Gateways is proposed. Two modules are involved in this binding model, namely search engine and configuration. Search engine aims to find the suitable gateways from registry where is used to register and publish all the gateways installed in a manufacturing shop floor, plant or enterprise. Configuration is responsible for binding the information relationship between WIPA and the selected suitable gateways. After configuration, the WIPA and selected gateways could know where inputs are obtained from and the captured real-time information is sent to respectively.

3. Critical Event Model

It is used to help users to obtain more meaningful and actionable information from large amount of low level events and to control the event-driven information systems. It establishes an aggregation of series of the events from agent-based smart object to form high level events. Critical event is composed by two main parts: definition and executer. Definition is used to create new composite event types by establishing the relationship among the events of agents. The relationship includes information, logic and sequences flows and is also described in a unified model called ceXML schema. Executer acts as an event engine and is used to execute critical event according to the pre-defined ceXML.

According to the requirements of WIPMS, four types of critical events are defined. The first is manpower regulation, which is responsible for establishing the events of gateways relevant to employees. The useful information such as productivity of each operator can thus be tracked and traced. The second is equipments regulation. It reflects the information of all the equipments by compositing the events of gateways related to equipments. Through this critical event, the information of corresponding equipment such as dynamical capacity and produced WIP items can be tracked and traced. The third is materials regulation. It is used to track and trace the status and history of each material. The fourth is production regulation. It can be used to track and trace the WIP inventories and product progress of the shop floor on the one hand, and monitor the production disturbance on the other hand.

9.6 Case Study

This section builds a proof-of-concept demonstration to describe how the presented Smart Gateway works and how to implement real-time visibility and traceability of WIP. The motivating scenario uses our previous research work reported in the international journal of computer integrated manufacturing [8].

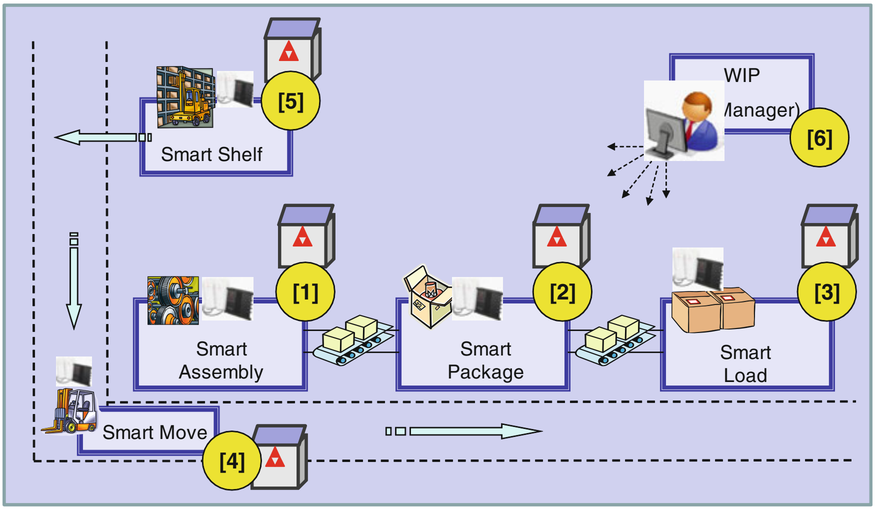

Fig. 9.8 Overview of the motivating manufacturing shop floor [8]

9.6.1 Description of Motivating Scenario

The motivating scenario is about a flexible manufacturing system (FMS). For simplicity of understanding but without loosing generality of principle, some basic manufacturing resources are selected for configuring a practical proof-of-concept demonstration. The configuration of the FMS depends upon the structure of the product (variant) to be assembled. As shown in Fig. 9.8, this demo FMS consists of the following main components, namely,

- Three main workstations (for assembling, packaging and loading van toys, respectively), denoted as (1), (2) and (3) in Fig. 9.8;
- One trolley for shop-floor logistics, denoted as (4) in Fig. 9.8;
- One shelf for storing raw materials and WIP items, denoted as (5) in Fig. 9.8.

9.6.2 Configuration of RFID-Enabled Ubiquitous Manufacturing Shop Floor

In order to create a RFID-enabled smart ubiquitous manufacturing shop floor, it is first necessary to identify shop-floor objects to which RFID tags and/or readers and/or other types of wireless devices are attached. RFID tags are deployed in several ways.

For RFID tags, firstly, staff members have their staff cards which can be read and written by the RFID readers. Secondly, one of the components in the product assembly is considered critical and each critical component is attached with a RFID tag. This tag, as a mobile memory of the "smart" WIP products, plays important roles throughout the assembly process and even retained for subsequent supply chain applications. Thirdly, RFID tags are attached to all the pallets for holding WIP materials, including components/parts, scraped materials, and semi-finished subassemblies and finished product assemblies. These tags are not only used for tracking the flow of materials but also for controlling the WIP inventories. Such field information will in turn be fed back and used for production planning and scheduling. Finally, each location of shelf is attached with RFID tags. These tags are used to bind the information between the location and the materials at this location.

For RFID readers, as described previously, they should be integrated to a gateway and wrapped as corresponding web services so that they can be easily invoked for capturing real-time manufacturing information. The detailed procedure of how to wrap smart objects integrated into Smart Gateway and publish them to registry can be seen in our relevant paper [2]. In this case, it is assumed that each workstation is equipped with a Smart Gateway that hosts one RFID reader. This gateway is multi-functional and is able to read tags attached to different objects. Smart Gateways are also available at the shelf for capturing the real-time information of the tags attached to different objects. Finally, trolley with which pallets are moved across the shop floor is equipped with a gateway.

After the configuration of SOs and the five gateways, it is ready for creation of WIPA and establishing the binding relationship between WIPA and Smart Gateways. As seen in Fig. 9.8, there are five gateways placed at the different manufacturing resources for capturing real-time manufacturing information in the scenario shop floor, denoted as Smart Gateway (1) to Smart Gateway (5).

9.6.3 Creation and Configuration of WIPA

Three main steps are needed for creating an instance of WIPA as seen in Fig. 9.9. Firstly, a WIPA instance should be created according to its information model. In this stage, data source service plays a very important role because the required manufacturing information is stored in various EISs with different database. For example, the production plan is stored in ERP whose database is Oracle, CAPP information is stored in PDM that uses SQL Server as its database, and advanced planning scheduler is stored in MES that uses My SQL database. The created WIPA instance establishes the information relationship between WIPA and corresponding manufacturing objects based on the hierarchy and data structure designed before. Two types of information, namely static and dynamic information, are involved in the formed instance of WIPA. Static information refers to the information that seldom changes during execution unless the exception occurs, for example, CAPP, production plan. The dynamic information refers to the information that timely changes, for example, consumed materials, produced products/semi-products, etc.

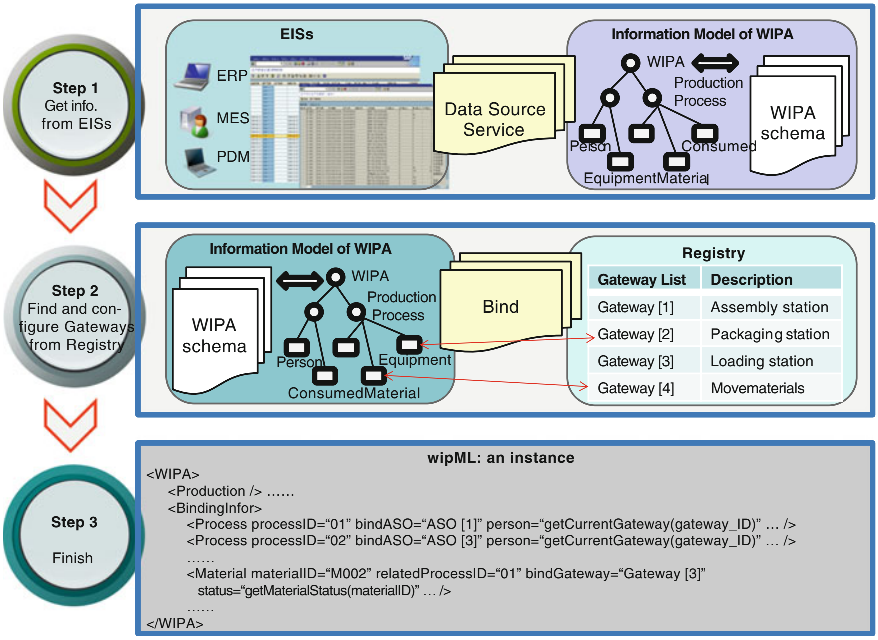

Fig. 9.9 Procedure of creating a WIPA instance [8]

Then, for each dynamic information node of the WIPA instance, the gateway data service component is used to find and bind the suitable Smart Gateways for providing the real-time manufacturing information to this node. During the execution, the real-time data capturing or updating operations can be conducted by invoking the methods of the gateway data service. And this node can thus be timely updated as well as the binding gateway can timely receive the information from WIPA.

After all the involved dynamic information nodes of the WIPA are configured by this way, an XML-based definition file is created which records the bind relationship between the nodes and gateways.

9.6.4 Real-Time WIP Management

For better understanding, let us describe a scenario to demonstrate how the presented Smart Gateway and WIPMS facilitate the real-time WIP management in this demo.

Supposing the RFID-enabled ubiquitous manufacturing shop floor will produce some van toys and packaged them to container for transporting to customs, the corresponding workflow could be described as following:

1. Production material supply

This process is executed by internal logistic operators who are primarily responsible for choosing and executing the internal logistics orders to move WIP items between shop floor inventories and buffers of production workstations. During the moving execution, each activity such as picking up materials, current location and unloading materials are tracked and traced. In addition, the relevant information of the accurate number and type of materials picked up from which location of the warehouse and unload them to which location of the shop floor at which time by which operator etc. is also tracked and traced for WIP management.

2. Production-van assembly

Because the Smart Gateways installed at the different stations in the assembly line work in more or less similar way, let us study on the Smart Gateway [1] of the assembly station for assembling van. The real-time visibility explorer will provide intelligent navigation for assembly operator, and the relevant process could be described as following.

At the beginning, the assembly operator comes to this station and uses his staff card for login. Workstation Explorer will prompt the operator to check his assembly tasks when he accesses, as seen in Fig. 9.10a.

Before assembly, the operator needs to check all the required items needed by the facilities provided by workstation explorer seen in Fig. 9.10b.

If all the required items are checked successfully, a detailed assembly process prompts to illustrate how to assembly a van as shown in Fig. 9.10c. For example, this assembly process includes the following steps:

Step 1: Get a van body from the in-buffer of this workstation;

Step 2: Get a wind shield from the in-buffer of this workstation and put together with the van body to form a new WIP item;

Step 3: Get a roof from the in-buffer of this workstation and be added to the new WIP item formed in Step 2 to produce the finished product "van".

After each finished product is produced, the real-time visibility explorer will prompt the operator to put it into the out-buffer of this station, as seen in Fig. 9.10d. These processes are repeated until all the assembly tasks of the operator are finished.

3. Real-time WIP monitoring and control (WIPMS explorer)

During manufacturing execution stage, the WIPMS Explorer is responsible for monitoring and controlling the entire shop floor according to the critical events. Its main users are shop-floor managers and/or assembly line supervisors. The WIPMS Explorer provides facilities mainly for information display and also acts as interface with corresponding ERP decision support modules. Therefore, its main function is to organize the real-time information captured from gateways installed at the corresponding manufacturing resources. The mechanism of organizing the real-time information in different ways to serve different purposes is based on the critical event model. As the user interface, the WIPMS Explorer is where the supervisors can sense the shop floor changes and disturbances. The supervisors can then take corrective actions by manually using corresponding APS explorers. As shown in Fig. 9.11, the WIPMS Explorer provides facilities for the manager/supervisor to monitor the following aspects of the assembly line:

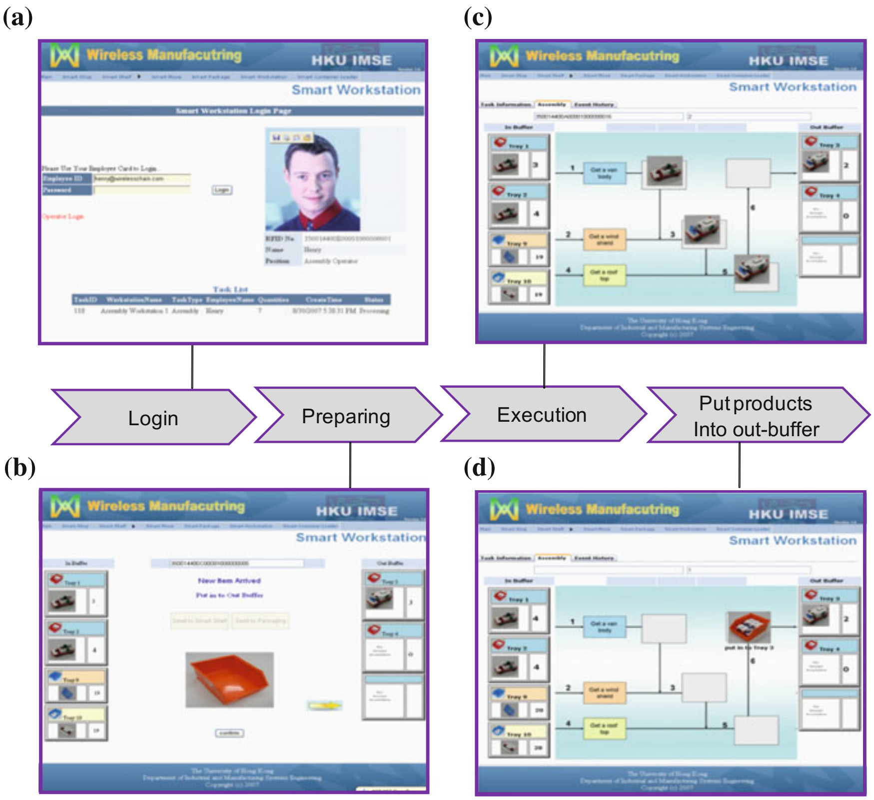

Fig. 9.10 Real-time visibility for van assembly at smart gateway (*1*) [8]

1. Real-time status of each smart workstation including total production demand and finished, current task in process, number of Scraps, wellness of each workstation, and current location of Smart Move, seen in Fig. 9.11a;

2. Real-time production process of each smart workstation including total demand and current output, number of scraps, net completed and percentage, and status of buffer, seen in Fig. 9.11b;

3. Real-time progress of production order including total demand of each component, total completed of each component and percentage of completion, seen in Fig. 9.11c;

4. Manufacturing event tracing including operational events of each individual Smart Workstation, i.e. event history record, and logistics between each two Smart Workstation, i.e. incoming material of each station and outgoing material of each station, seen in Fig. 9.11d.

The above functions allow managers and supervisors to monitor and control the production remotely if they are not at the shop floor as long as they have the access to the Internet.

Fig. 9.11 Real-time visibility and traceability of WIP [8]. **a** Real-time visibility of workstations **b** real-time visibility of product BCM **c** tracing information of materials **d** tracing information of product

9.7 Concluding Discussion

UM is emerging as an advanced manufacturing technology (AMT). It relies substantially on wireless smart objects such as Auto ID sensors/RFID and wireless information networks for the collection and synchronization of real-time field data from manufacturing shop floors. UM enables the shop-floor management to realize paperless working environment, real-time WIP tracing and tracking, and ultimately improve the efficiency and effectiveness of production supervision and decision and largely reduce the production disturbances.

This chapter has proposed a referenced UM infrastructure. Under this infrastructure, the overall architecture of Smart Gateway and WIPMS is presented for capturing the real-time manufacturing data and implementing dynamic WIP management. Following the service-oriented architecture, smart objects enabled ubiquitous manufacturing information infrastructure has been established. Through this infrastructure, both the upstream manufacturing information and the real-time manufacturing data of individual manufacturing resource could be obtained and captured by data source service and gateway data service respectively. Then, WIPMS can be used to implement real-time WIP tracing and tracking throughout the shop floor according to the specific production process. The successful proof-of-concept demonstration has allowed us to gain useful insights and experience. The prototype provides a foundation to migrate to a successful real-life industrial environment as an actual application.

The current work will be further extended in our future research from the following aspects. Firstly, the proposed data source service has only revealed a concept and applied to some open source EISs, and a great effort should be needed to support more various EISs of different companies. In addition, up-level decision based on timely shop-floor WIP information should be investigated for optimal production control. For example, real-time production scheduling/re-scheduling, real-time internal logistics planning and scheduling etc. Finally, data mining for production prediction based on real-time execution information monitored by critical event should be taken into account for reducing shop floor disturbance, e.g., how to implement production exceptions alerts and quality control in a real-time manufacturing environment.

Acknowledgments The relevant research contributions reported in a series of our international journal papers [2, 7, 8] have been used and integrated in this Chapter, authors would like to acknowledge the researchers and students in the Department of Industry and Manufacturing System Engineering of the University of Hong Kong. Besides, authors would like to acknowledge financial supports of the HKSAR ITF (GHP/042/07LP) grant and National Science Foundation of China (51175435).

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Chapter 10
Survey on Distributed Collaborative Engineering and Applications

W. M. Shen, Q. Hao and Weidong Li

Abstract Nowadays, product design and manufacturing industries have shown increasingly strong requirements of using new Information and Communication Technologies (ICT) to address more complex collaborative product development processes and higher expectation of customers dispersed globally. A new research area called Distributed Collaborative Engineering (DCE) has emerged in recent years in response to the aforementioned trend. Based on the rapid advancement of ICT, such as Internet, Web and Cloud Computing, DCE has become one of the most active and emerging R&D areas in the past two decades facilitating product design and realization processes, with a bid to support relevant teams to carry out distributed collaborative work effectively. DCE has progressed dramatically, and more and more research and engineering systems have been developed in order to achieve the full potential of DCE for various industrial applications. Rooted from Concurrent Engineering or Simultaneous Engineering, DCE has been expanded in terms of depth and width, and relevant research and engineering systems are now far beyond traditional definitions and working scopes. This chapter presents a review of the R&D literature in the area, from the developed technologies of the 1980s to today's state-of-the-art. Research challenges and opportunities are also discussed and highlighted in the end.

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10.1 Introduction

During the past two decades, product design and manufacturing processes have experienced many major technological innovations and paradigm shifts. The most recent R&D cycle starting from the end of last century is to renovate related design and manufacturing planning systems to be distributed collaborative through embedding the quickly developed Information and Communication Technology (ICT). Distributed Collaborative Engineering (DCE) is a new concept of optimizing engineering processes with objectives for better product quality, shorter lead-time, more competitive cost and higher customer satisfaction. The DCE concept and relevant methodologies have been widely applied to product design, manufacturing, construction, enterprise collaboration, and supply chain management. Particularly, applications of DCE to product design and manufacturing are becoming more promising. The depth and width of DCE is far beyond the traditional definition of Concurrent Engineering or Simultaneous Engineering [1]. DCE aims to meet the increasing demands of globally distributed collaborative design, the outsourcing trends in manufacturing, and closer interactions between design teams and customers for product requirement definition and model improvement. In a distributed collaborative system, designers and engineers can share their work with colleagues distributed globally via the Internet/intranet, and work with them together simultaneously or according to pre-defined workflows. Furthermore, these systems also allow designers to work closely with suppliers, manufacturing partners, and customers across enterprises' firewalls to get valuable inputs into the design chain. With a broader vision, distributed and collaborative Computer-Aided Design (CAD), Computer-Aided Engineering (CAE), Computer-Aided Manufacturing (CAM), Enterprise Resource Planning (ERP), Product Data Management (PDM), and Product Lifecycle Management (PLM) systems can be integrated to form distributed collaborative product commerce, which supports intra- and inter- enterprise applications across the whole product lifecycle. Meanwhile, DCE is carried out not only among multi-disciplinary product development teams within the same company, but also beyond the boundaries of companies and time zones.

Based on the first-hand research and industrial experience in this area, R&D overview of the field will be developed and research challenges and opportunities of the future will be discussed in this chapter. The rest of this chapter is organized as follows: Sect. 10.2 provides a brief overview of the DCE field; Sect. 10.3 reviews the pre-DCE technologies from 1980s; Sect. 10.4 describes today's state-of-the-art; Sect. 10.5 discusses future research opportunities and challenges; and Sect. 10.6 presents some concluding remarks.

10.2 Overview of Distributed Collaborative Engineering

Traditional product design and manufacturing planning systems use a sequential mode for model or plan generation. It breaks design or manufacturing planning tasks into a number of inter-connected tasks that can be sequentially executed in a pre-defined workflow. Recently, such a sequential mode has been found to be brittle and inflexible, such that, it often requires numerous iterations that make design and manufacturing planning expensive and time-consuming, and also limits the number of product alternatives that can be examined. On the other hand, sequential design and manufacturing planning is usually practiced with a down-stream-wised information flow. Information feedback from downstream operations (e.g., process planning or manufacturing at the shop floor) to the upstream design is usually performed by human interactions. It may cause insufficient and inefficient design on manufacturability evaluation/optimization and hence inefficient product development due to the absence of manufacturability checks at the design and manufacturing planning stage based on available resources.

In order to resolve the above issue effectively, new strategies have been developed such as DCE. DCE, which could be called or closely related to Computer-Supported Cooperative Work, Cooperative Design and Manufacturing, Concurrent or Simultaneous Design and Manufacturing, or Inter-disciplinary Design and Manufacturing, is the process of designing and developing a product through collaboration among inter-disciplinary product developers associated with the entire product lifecycle and the global locations. A distributed collaborative system could include those functions such as preliminary design, detailed design, manufacturing planning, assembly planning, testing planning, quality control planning, and product service planning as well as those from suppliers and customers [2]. An important objective of DCE is to address the insufficient or even absent manufacturability checks concurrently through detecting and considering conflicts and constraints at earlier design stages. To support DCE, ICT is used to augment the capabilities of the individual specialists, and enhance the ability of collaborators to interact with each other and with computational resources. DCE is not only compulsory for complex products such as the Boeing 777 airplane development, which involved 130,000 parts, 6,800 internal people and more than 10,000 external people, but also quite helpful for many middle- or even small-size products such as tooling, and electronic products [3]. With the globalization of the manufacturing industry, DCE is required to support integrative, distributed collaborative design and manufacturing. Therefore, integration, interoperability, distribution and collaboration are the major characteristics of DCE.

Members on a collaborative team often work in parallel and independently using different engineering tools [4, 5]. Engineering design and manufacturing planning have some unique characteristics (e.g., diverse and complex forms of information, inter-disciplinary collaborative skills and backgrounds, and heterogeneous software tools), which make interactions difficult to support. Traditional approaches to sharing design and manufacturing information among collaborators and their tools include the development of integrated tools and the establishment of common data standards for exchange. These approaches are not good at supporting effective collaborative design because of the highly distributed nature of the design teams and engineering tools as well as the complexity and dynamics of design environments. A successful implementation of DCE needs a series of new integration strategies, including an efficient communication strategy for a multidisciplinary group of people from the design and manufacturing departments to be integrated through sharing and exchanging ideas and comments, a system integration strategy to link heterogeneous software tools in product design, analysis, simulation and manufacturing planning and optimization to realize obstacle-free engineering information exchange and sharing, and an interoperability strategy to manipulate downstream manufacturing applications as services to enable designers to evaluate manufacturability or assemble-ability as early as possible [6]. On the other hand, the objective of a design team has multiple facets, for example, optimizing the mechanical function of the product, minimizing the production or assembly costs, or ensuring that the product can be easily and economically serviced and maintained. To achieve global satisfaction, cooperative strategy, such as negotiation, optimization and trade-off, is an important research issue in DCE.

A DCE system cannot be simply set-up through equipping a standalone design or manufacturing system with ICT and communication facilities. Due to the complexity of collaborative design and manufacturing planning activities and the specific characteristics/requirements of the standalone systems, it needs some innovations or even fundamental changes in many aspects of the standalone systems, such as infrastructure design, communication algorithms, geometric computing algorithms, etc. In Table 10.1, some major differences between standalone and distributed collaborative systems are highlighted. A distributed collaborative system needs two kinds of capabilities and facilities: distribution and collaboration. These two terms emphasize the different aspects of a system: physically, the former separates systems as geographically dispersed and expands them to support remote design activities, and, functionally, the latter associates and co-ordinates individual systems to fulfill a global design target and objective. In the aspects of enabling technologies, distribution is more fuelled by the development of ICT, such as Java, .Net, Web, XML, Web service and Cloud Computing technologies, and collaboration is more driven by the design and development of effective collaboration mechanisms to facilitate human–human/human–computer relationships. However, although having different focuses, they are closely inter-related and complementary. A collaboration mechanism needs the specific design of the distributed architecture of a system to meet the functional and performance requirement.

Synchronous and asynchronous communications are two primary modes to bolster collaborative activities. Synchronous tools enable real-time communication for users to work together in the “same time-different place”, therefore, to meet some efficiently collaborative requirements. The primary drawbacks of this manner include that it tends to be costly and requires a large bandwidth to realize efficient connection and cooperation, and the same-time participation organization

Table 10.1 Comparisons on standalone and distributed collaborative systems

Items for comparisons	Standalone systems	Distributed collaborative systems
Application status	2D or 3D systems are popularly used in product design and development	The systems are not generally accepted due to the weakness in interactive capabilities, security of data, real-time and convenient collaboration, etc.
R&D status	Mature for geometric modeling. R&D focuses on knowledge-based modeling technologies and some engineering application tools in mould, die, etc.	R&D focuses on developing new technologies in feature- and assembly-based representation, system infrastructure, effective distribution/collaboration algorithms and geometric streaming in the Internet
Data and system structures	Centrally stored design models	Distributed design models in different geographical sites
	Standalone architecture	Client/server architecture
Process organization	A hierarchical organization is used to coordinate information workflows in different design and manufacturing departments	Hierarchical or horizontal collaboration is used to coordinate information and design activities among different design and manufacturing, or design and design departments
		Data exchange standards, Internet and Web technology, distributed intelligent (such as multi-agent) technologies, etc., are used to establish a distributed integrated system
Modeling functionalities	2D and 3D modeling capability to support detailed design	Systems can be classified as two levels: visualization-based product discussion systems and simultaneous collaborative design systems
Geometric streaming distribution	The need is not apparent	Necessary. Distributed systems need real-time and interactive operations
Market model	Users need to buy and install the packages of systems locally	New business opportunities and models can be brought. DCE systems can be designed as Cloud-based services for short-term or long-term renting

and conflicting schedules are quite challenging. Asynchronous tools can enable communication and collaboration to happen in the "different time-different place". This manner brings convenience for users to work together based on their own schedules and time with the instantly accessible resources and less bandwidth requirements. Some histories of the interactions of a working group can be captured and recorded as backup information. The limitation of this manner is that users might have the impersonal feelings when they prefer higher-touch manners. Therefore, these two manners can be selectively used in the different collaborative design stages to meet some particular requirements of participants.

10.3 DCE in the Past Decades

This section provides an overview of the related research fields, including CSCW (Computer Supported Cooperative Work), Concurrent Engineering, HCI (Human–Computer Interaction), etc., which triggered the emergence of DCE.

10.3.1 Computer Supported Cooperative Work

According to Schmidt and Bannon [7], collaborative supported cooperative work was first used by Greif and Cashman in 1984 to describe the topic of an interdisciplinary workshop that they were organizing on how to support people in their work arrangements with computers [8]. In fact, many people simply refer to this area by the term of Groupware, though others consider this to be too narrow. Generally speaking, the term Groupware is widely used in commercial software products while CSCW is used more in the research community.

10.3.2 Concurrent Engineering/Simultaneous Engineering

The concept of Concurrent Engineering or Simultaneous Engineering was initially proposed in the late 1980s as a potential means to minimize the product development time. It was defined as "a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support" [9]. In a concurrent engineering environment, techniques, algorithms and software tools are connected to allow product designers and developers to interact with each other. With concurrent engineering, more time and money are usually spent in the initial design stage to ensure the overall optimization of concept selection. Product design changes can be reduced at the late stages, leading to better engineered products with better total quality, time and cost competitiveness. There are a number of implementation strategies, from the parallelization of product lifecycle functions to the upfront consideration of DFX activities such as design for manufacturability, assemble-ability, serviceability, and recycle-ability, to the cooperation and coordination of product design teams with different expertise [8–10], which has laid a solid foundation for DCE. To ensure the success of concurrent engineering, more emphasis is put on the establishment of teamwork culture between design and manufacturing teams, and the enhancement of quick and effective communication. Balamuralikrishna et al. [11] summarized concurrent engineering as three T's: tools, training and time. Tools refer to the communication facilities between the personals in the multidisciplinary departments to address the information exchange that is obstructed by the complexity and wide range of specialized disciplinary areas and interdependent activities. Training provides a mechanism for employees to work collaboratively and concurrently, making the best use of the company's resources. Time means corporations need time to carefully investigate and plan concurrent engineering as it involves many complex software tools and information infrastructures. Many reported cases have shown that a hurried implementation of concurrent engineering usually bring high probability of backfiring. In industry, more companies have realized the great benefits of concurrent engineering. Honda Racing F1 Team's new development process is one of the good examples by UGS PLM [12].

10.3.3 Human–Computer Interaction

Research on Human–Computer Interaction (HCI) was started as early as computers were invented. Myers [13] presented a brief HCI history in 1998. However, there is currently no widely agreed definition that covers a full range of topics that form the area of HCI, from computer graphics to ergonomics, and from virtual reality to digital human modeling. Computer graphics was born from the use of CRT and pen devices very early in the history of computers. Work in computer graphics has continued to develop algorithms and hardware to allow the display and manipulation of ever more realistic-looking objects—which led to rapid developments of CAD/CAM tools in the 1980s. There are many HCI related international conferences with the most widely recognized one called HCI International Conference Series [14].

With its initial R&D focus on interaction between one user and one computer, HCI R&D was then extended to human–human interaction via networked computers, which is, in fact, the essence of DCE.

10.3.4 Blackboard, DAI and Software Agents

The blackboard architecture was proposed in the HEARSAY project [15] as a means to organize and control large Artificial Intelligence (AI) systems. Its first version HEARSAY I was used for speech recognition based on the idea of cooperating independent acoustic, lexical, syntactic, and semantic knowledge sources.

The introduction of the Contract-Net is a milestone in the history of Distributed Artificial Intelligence (DAI). The Contract-Net protocol was developed by Smith [16] in 1980 and demonstrated on a distributed sensing system. The Contract-Net implemented a negotiation-based approach for allocating tasks dynamically to nodes in the network. When a node has to solve a problem for which is beyond its expertise, it broadcasts a task-announcement message that describes the task to be solved. Nodes that receive the message and wish to solve the problem then return a bid message. The node that issued the task-announcement message, called the manager, waits for bids for a certain period and then selects one (or more) bidder(s) to do the task, who is called the contractor. Thus, the choice of the contractor is done after the selection by the manager and by mutual agreement. To be able to function correctly, the system must include a high-level protocol that defines several types of messages with a structured content. Contract-Net has been widely used in various agent systems for negotiation among agents.

The Contract-Net protocol offered an early practical means for dealing with open systems from a software engineering point of view. Contrary to the blackboard approach, there is no shared memory where data and partial results are made available to the various knowledge sources. The Contract-Net approach has separate knowledge sources attached to distinct nodes in a computation network.

The actor model proposed by Hewitt [17] offers a model of computation for open systems at a finer grain than the Contract-Net approach. In the actor approach, problem solving is viewed as the result of the interaction of the activities of knowledge sources working independently and locally (with limited expertise and limited knowledge). Each node communicates with a limited number of other knowledge sources.

The concept of agents is evolved from the concepts of blackboard, Contract-Net, and actors. Separately, in applied fields such as manufacturing, object-oriented systems were developed with increasing intelligence being incorporated into the objects. What began as passive objects became ‘active objects’ or ‘rule-based objects’ or ‘intelligent objects’ and finally ‘intelligent agent objects’ as this stream of evolution merged with that of DAI [18]. All these technologies provide a good foundation for developing collaborative design systems. Under this context, an agent can be considered as a software system that communicates and cooperates with other software systems to solve a complex problem which is beyond the capability of each individual software system [19].

10.3.5 More Developments

Modern design, particularly engineering design, is intrinsically multidisciplinary [20]. Various tools such as CAD/CAM/CAE tools, developed and commercialized by different vendors without common specifications (or even with intentionally defined unique specifications for self-protection), do not address the needs of multidisciplinary design. On the other hand, large organizations like Boeing, Airbus and GM, must find a way to coordinate their research and development teams which are geographically distributed around the world in an effective way to carry out new product developments within a very limited time frame. Technologies like intelligent agents have been investigated to address this need, particularly to enhance communication, cooperation, and coordination among design team members as well as software tools. Some tools like groupware were directly used to facilitate the communication among engineers and designers. Software agents were used to integrate different engineering tools. Examples of early applications of software agents in collaborative design include PACT [21], DIDE [22], and SiFAs [23].

With its emergence around 1993, the Web was quickly applied in the development of collaborative design systems, particularly for geographically distributed designers to share design documents. Along with the Web, a number of associated representation technologies have been developed, such as HTML (Hyper Text Mark-up Language), XML (eXtensible Mark-up Language), VRML (Virtual Reality Mark-up Language), to enable better cross-platform and -enterprise exchange of multi-media information and design models. In terms of system infrastructure, many early collaborative design systems were also developed using the Blackboard architecture and distributed object technologies like CORBA and COM/DCOM.

10.4 DCE in the New Era

During the past fifteen years, a large number of distributed collaborative systems have been developed and reported based on the technologies of Web, software agents, and recently Web Services, Semantic Web, Computing Grids and Cloud Computing for design and manufacturing distribution and collaboration. A few vendors and other software firms also started developing and promoting distribute and collaborative tools, for example, AutoDesk's InventorTM [24] and BuzzsawTM [25], Streamline [26], ArchiCAD TeamWorkTM [27], CoCreate's OneSpace Solution [28], Matrix PLM Platform [29], and UGS's PLM solutions [30]. The following subsections present a brief review of these researches, developments, and applications.

10.4.1 DCE for Collaborative Design and Manufacturing

DCE has been a very active research field during the past two decades. Design and manufacturing planning (particularly engineering product design) has been one of the most important applications of DCE technologies. The most widely used DCE techniques include groupware techniques for facilitating communication among design team members and context awareness techniques for enhancing coordination among team members.

10.4.2 Web-Based Collaborative Design and Manufacturing

The Web was originally developed for information sharing within internationally dispersed teams and the dissemination of information by support groups. Proposed and developed early in the 1990s, the Web has quickly become a convenient media to publish and share information relevant to the design process, from concept generation and prototyping to virtual manufacturing and product realization. It has been adopted as the most popular implementation architecture of a collaborative product development (including design and manufacturing) tool. A distributed collaborative system developed with the Web as a backbone will primarily provide: (1) access to catalogue and design information on components and subassemblies; (2) communication among multidisciplinary design team members (including customers, designers and production engineers) in multimedia formats; (3) authenticated access to design tools, services and documents. However, since the Web is still fast evolving, particularly with the development of Web services and Semantic Web technologies, many researchers and working groups in and outside W3C are working hard to improve the current Web infrastructure and supporting tools. Web-based infrastructure has been used in a number of collaborative product design systems. In most cases, the Web is primarily used by multidisciplinary team members as a medium to share design data/information/knowledge; while in some cases, it is integrated with other related technologies and is used for product data management and project management.

A comprehensive review of some Web-based tools and systems can be found in [4, 31]. Most Web-based collaborative design and manufacturing systems are developed using Java and CORBA [32–34], some others are developed by Common Lisp (WWDL [35]), and Prolog (WebCADET [36]). In addition to HTML and Java Applets for developing client side user interfaces, ActiveX [37, 38] and VRML [39, 40] are widely used.

However, the Web technology alone is not a complete solution to collaborative design systems, although it makes communication physically viable through a common network. In order to collaborate on a distributed design project, remote engineers and designers need active supports to coordinate their efforts. This coordination involves the translation of terminology among disciplines, locating/providing engineering analysis services, virtual prototyping services, and project management [41–43]. Web servers should not only be a repository of information but also provide intelligent services to help users to solve design problems. Such servers may be called software agents that will be discussed below.

10.4.3 Agent-Based DCE

Application of software agents to collaborative design has been demonstrated by various research projects. PACT [21] might be one of the earliest successful projects in this area. The interesting aspects of PACT include its federation architecture using facilitators and wrappers for legacy system integration. SHARE [44] was concerned with developing open, heterogeneous, network-oriented environments for concurrent engineering, particularly for design information and data capturing and sharing through asynchronous communication. SiFAs [23] was intended to address the issues of patterns of interaction, communication, and conflict resolution using simple single function agents. DIDE [22] was developed to study system openness, legacy systems integration, and distributed collaboration. ICM [45] developed a shared graphical modeling environment for collaborative design activities. Co-Designer [46] was intended to support localized design agents in the generation and management of conceptual design variants. Concept Database [47] described a strategic design support for version control, workflow management and information gathering. A-Design [48] presented a new design generation methodology, which combines aspects of multi-objective optimization, multi-agent systems, and automated design synthesis. It provided designers with a new search strategy for the conceptual stages of product design that incorporates agent collaboration with an adaptive selection of design alternatives. Some projects also addressed the issue of integration and collaboration among product design, process planning, and manufacturing scheduling [49–51].

In agent-based collaborative design systems, software agents are mostly used for supporting cooperation among designers, enhancing interoperability between traditional computational tools, or allowing better simulations (particularly distributed simulations). The book on "Multi-Agent Systems for Concurrent Intelligent Design and Manufacturing" [52] provides a detailed discussion on issues in developing agent-based collaborative design systems and a review of several well-known projects or systems.

10.4.4 Team Management and Development Coordination

In DCE systems, team management and design coordination functions are the crucial components for establishing a well-organized team to conduct a collaborative design task.

A working session mechanism is effective for the team management. Each session can be used to organize a collaborative task, and designers in the same session can share the design information dynamically [53–55]. In a system, different design tasks can be carried out at the same time in different sessions. In a session, designers can play as different roles such as project leader, members and supporters. A project leader is responsible to manage a session and supervise the whole design process, and he/she is authorized to schedule the process and avoid deadlocks during design due to network problems. A design member can carry out the design collaboratively, and a supporter can provide comments for the design or resources required arising during the collaborative design. Messaging is an important assistance functions for collaborative design [53, 56, 57]. Through messages in text, video or audio, designers in a session can communicate with each other to exchange design ideas.

Several mechanisms are used for design coordination. A control token mechanism has been utilized in [53–55] to schedule a collaborative design activity. Each session has a control token, that is, at any one time, only the user who holds the control token is the active designer and can edit a part; whilst the other users in the same session only receive the updated information and are observers. The user who is carrying out the edition function can become an observer by transferring his control token to another user. The advantage of the control token mechanism is that design conflicts can be avoided during a simultaneous process, and the disadvantage is the low efficiency. Another mechanism is based on an agent system. Mori and Cutkosky proposed an agent-based system to coordinate design based on the theory of Pareto optimality [58]. The agents are reactive and they can track and respond to changes in the state of the design when any designer changes his model and brings the conflicts. However, the communicating between designers through the agent system is simple and limited, and this architecture is not suitable some complex design activities. A version control mechanism was attempted in [59] whilst a synchronization mechanism is under development. In a situation when designers are working for different sub-assemblies, Shyamsundar and Gadh [60] and Chen et al. [61] defined a set of new assembly representations to constrain the design assemblies assigned to individual designers, further to form a whole collaboratively developed assembly. Meanwhile, methodologies to detect and manage conflicts arising from a collaborative activity are investigated [62, 63].

10.4.5 Integration of Web and Agent Technologies for DCE

Both the Web and agent technologies are very useful in implementing collaborative design systems. The attractiveness of the Web for propagating information makes it appropriate to integrate with agents for accessing and manipulating information automatically. The challenge is to build a Web-based environment that enables and supports seamless interactions between human designers, software agents, and Web servers using the available emerging technologies [64].

A Web-based collaborative design system usually uses a client/server architecture, in which the interaction between components is predefined. This kind of approach is insufficient to support dynamic collaborative design environments, where tasks are usually involving complex and non-deterministic interactions, producing results that might be ambiguous and incomplete. An agent-based collaborative design system is a loosely coupled network of problem solvers that work together to solve problems that are beyond their individual capabilities [52]. Software agents in such systems are communicative, collaborative, autonomous (or semi-autonomous), reactive (or even proactive), and intelligent. Different system architectures have been proposed and used to implement agent-based systems. Some systems use approaches similar to the blackboard architecture or the client/server architecture, e.g., the Design Board approach in SiFAs [23]; the shared graphical modeling approach in ICM [45]; and the shared database approach [47]. Most systems use federated system architectures, e.g., a facilitator approach in PACT [21] and a mediator approach in ABCDE [48]. A few systems use the autonomous agent approach [22].

Although agent technology has been recognized as a promising approach for developing collaborative design systems, those agents that have so far been implemented in various prototype and industrial applications are actually not very "intelligent". In this view, agent applications in Web-based collaborative design field are still facing many challenging questions. WebBlow [64] is an interesting attempt on the integration of the Web and software agents in implementing a multidisciplinary design optimization environment [65, 66]. Before the emergence of Web Services, the concept of active Web server was proposed to integrate the Web and agent technologies [67]. Since the active Web servers have very similar features of Web Services, it is nature for the further work to implement collaborative design systems using Web Services [68].

During the past 10 years, more and more collaborative design systems have been developed using Web Services as well as Semantic Web and Grid Computing techniques. It is now easy to find hundreds of publications on this topic, e.g., there were more than 30 related papers presented at CSCWD 2006 [69] and more than 40 at CSCWD 2007 [70].

10.4.6 New Representation Schemes for DCE

In a collaborative design process, product models need to be disseminated in a broader scope. Product models are the most important knowledge and properties of the product development companies, so companies are usually reluctant to share these models directly to avoid the leakage of the commercial secrets to competitors. This consideration makes it difficult to realize the full potentials and benefits of collaboration. On the other hand, a product model is proprietary to a distribute and collaborative system. In a collaborative design environment with multiple users, it is infeasible or uneconomical to install a distributed collaborative system for every user to view or manipulate the product model. To address these concerns, research efforts have been made to develop new representation schemes of product models based on VRML, including X3D (eXtensible 3D) [71], W3D (Web 3D) [72], U3D (Universal 3D) [73], JT [74], and OpenHSF [75]. These representation schemes retain the essential visualization information of proprietary product models to support display-based manipulations, such as rotation and zooming, annotation, and mark-up. Most of these schemes are open in formats and the features inside are neutral so that they have much broader acceptance than those of the proprietary product models. Major applications of these schemes for collaboration include customer survey on product concepts and initial models, high-level project review among management, development and service departments, sale promotion, e-documents (e.g., Acrobat 3D), sharing catalogue, and visualization functions in Product Data Management/Product Lifecycle Management (PDM/PLM) systems. Since only the visualization information is included in these schemes, crucial design information is protected.

10.4.7 New Visualization Systems for DCE

In order to support the new representation schemes, some new visualization systems have been developed, e.g., Cimmetry Systems AutoVue [76], Actify SpinFire [77], SolidWorks eDrawing [78], RealityWave ConceptStation [79], and Autodesk Streamline [26]. The visualization-based platforms are cost-effective solutions to replace CAD systems to facilitate collaborative activities for various users. With the new representation schemes and visualization systems, teams can collaborate more effectively, such as taking on design discussions, reviewing new products, and conducting customer surveys to get design feedback as early as possible. This may overcome some drawbacks of proprietary CAD product models that hinder collaborative activities. A visualization-based collaborative system uses a two-tier or three-tier client/server architecture. Java Applet and Microsoft ActiveX technologies are widely used for developing Web-based or specialized clients. Core functions or services are implemented in Java Servlet or Microsoft .Net ASP at the server side to provide system support and maintenance [80–82]. Recently, Java3D has been widely used to enable visualization-based manipulations of 3D objects and scenes, e.g., to build, render and control 3D objects for Web-based collaboration [83, 84]. The list of visualization systems is shown in Table 10.2.

10.4.8 Product Data Management and Product Lifecycle Management Systems

Product Data Management (PDM) and Product Lifecycle Management (PLM) systems have been adopted by industry to facilitate engineering design. Such systems promised that the “right information” is provided to the “right person” in the “right time” according to the “right order”. Mainstream solutions include UGS TeamCenter [85], PTC Windchill [86], ENOVIA VPLM, ENOVIA MatrixOne and ENOVIA SmarTeam [87]. Actually, the systems can be regarded as the system-level integrated implementation of the current collaborative

Table 10.2 Characteristics and functions of web-based systems

Products	Characteristics and functions	Data distributed methods
Cimmetry Systems Autovue^{TM}	(1) A viewer for part and assembly models	3D streaming
	(2) View, mark-up, measure, explode, cross-section, etc	
InFlow ConceptWorks^{TM}	(1) An add-on viewer to SolidWorks	3D streaming
	(2) View and mark-up	
Actify SpinFire^{TM}	(1) A viewer for part models	Download
	(2) View, cross-section, measure, grid and ruler	
SolidWorks eDrawing^{TM}	(1) A viewer for native or simplified SolidWorks files	Download
	(2) View, mark-up, measure, 3D pointer, animation	
Adaptive Media Envision3D^{TM}	(1) A viewer for part models	3D streaming
	(2) View, mark-up, redline, chat	
Centric Software Pivotal Studio^{TM}	(1) A base platform to provide a workspace manager, a project organizer and a viewer for part models	Download/3D streaming
	(2) View, mark-up, video/audio conferencing, chat	
Hoops Streaming Toolkit^{TM}	(1) A toolkit to provide 3D streaming APIs	3D steaming
	(2) BaseStream class library, advanced compression, attribute (color, texture) support, object prioritization, etc	
RealityWave ConceptStation^{TM}	(1) A VizStream platform, which consists a server and a client	3D streaming
	(2) View, mark-up, message	
Autodesk Streamline^{TM}	(1) A platform based on the VizStream	3D streaming
	(2) View, measure, bill of materials	

technologies to support engineering design [88]. These systems have distinguished characteristics, but they share the following common functionalities as follows:

- Team management—to map the structure of a product development team to a hierarchical structure of organizations;
- Product structure management—usually a Bill Of Materials (BOM) structure root, to represent the physical structure of a developed product at different levels, which generally contains assemblies, subassemblies and components;
- Workflow and process management—to allow an organization to automate procedures in which information, tasks, and documents are passed among participants;
- Design change management—to manage change information in design processes;
- Visualization-based collaborative workspace—to retain the visualization information of product models based on light-weight visualization schemes to support multiple users to manipulate the product models, such as rotation, measurement, annotation, and mark-up;
- Integration interfaces with CAD, shop floor execution systems, legacy enterprise information systems, and other partners on the product value chain.

From a research perspective, important issues need to be solved for the better application of PDM/PLM systems. Design process, along with the product itself, should be considered as a crucial component of an engineering enterprise's intellectual capital [89]. Five aspects of design processes have been studied, including support for design information transformations, support for design decision-making, modeling and representation of design processes, analysis of design processes and synthesis of design processes. Qiu and Wong [90] developed a dynamic workflow mechanism to accommodate the changes during design by minimizing repetitive execution of finished workflow nodes. This approach can address the data integrity issue by managing various workflow data such as node properties and scripts. Concurrency control is the foremost mechanism to organize synchronous activities to avoid conflicts. Locking is a primary means in managing concurrency control to prevent people from colliding, and three types of locking, i.e., non-optimistic, optimistic and visual, have been developed and used in various applications. Negotiation can formalize and implement the mediation and facilitation functions among people to handle conflicts. Some research projects [88, 91, 92] have been carried out to enhance PDM systems to support pre- and post-design stages. Huang et al. [93] developed a Web-based system to manage Engineering Changes (ECs).

10.4.9 Product Data Exchange

STEP (Standard for the Exchange of Product Model Data) is an ISO standard that provides a complete unambiguous, computer-interpretable definition of the physical and functional characteristics of a product throughout its life cycle. It promises to ensure product data exchange among different computer systems and applications associated with the complete product life cycle including design, manufacturing, utilization, and maintenance. In order to deploy the Web infrastructure effectively and efficiently in collaborative product development systems, it is better to integrate STEP into the Web infrastructure. Although some research and development groups are working actively in this area, e.g., XML Transactions for STEP by STEP Tools Inc. [94], more fundamental research and development work is still needed in this area.

10.4.10 New ICT Architectures for DCE

The architectures for the developed collaborative CAD systems can be classified into three types:

- "Thin server + strong client"
- "Strong server + thin client"
- "Peer-to-peer"

In the first architecture, clients are equipped with whole system functions and some communication facilitators. A server plays as an information exchanger to broadcast design and manufacturing files or commands generated by a client to other clients during a collaborative design process. In the second architecture, the data structures in clients are light-weight and they primarily support visualization and manipulation functions (such as selection, transformation, changing visualization properties of displayed parts, etc.). The main modeling activities are carried out in a common workspace in the server side. A thin/strong representation in client/server respectively has been proposed to enhance the performance of the system effectively [54, 55]. The third architecture, including [63] and Inventor collaborative tool^{TM}, supports the sharing and manipulation of services or modules of a system by other systems. For example, for the Inventor collaborative tool^{TM}, an MS Netmeeting tool is embedded for the peer-to-peer communication and application sharing.

Considering the characteristics of distributed collaborative systems, the three architectures show potentials in different aspects. The implementation of the first architecture is the most straightforward comparing to the other two architectures. Through equipped with a communication facility, standalone systems can be conveniently re-developed as design clients and linked together by the server with information exchange and collaboration coordination functionalities. This architecture can effectively meet the requirement of design and manufacturing for real-time interactive operations since most of the geometric computing for modeling and modification is carried out in the clients locally. Meanwhile, it can support heterogeneous modeling systems in clients and a neutral information exchange format, for example, XML, can be designed for communication in the environment [95]. However, the adaptability of the architecture is not easily maintained. If a new user is added in the environment, a whole package of distributed collaborative system has to be added and configured. Meanwhile, such architecture is difficult to be migrated to the Web application. The second architecture is getting more popular since it brings a new kind of business model—application service provider (ASP). With such architecture, small and medium enterprises (SMEs) or even individual designers with specific domain knowledge can rent on-line high-end design and manufacturing systems, so they are able to participate and co-operate in the design process with large firms. The scalability of system can be enhanced since it is convenient to add new seats in the distributed system. The third architecture employed the peer-to-peer computing manner. Services of a peer with design and manufacturing function can be manipulated by another peer. The architecture is high-performed for point-to-point communication and collaboration. However, it is not suitable for a group of users to work together. Compared to the first architecture, the implementation difficulty of the last two is increased, whilst the scalability is enhanced.

10.4.11 Cloud Manufacturing

Cloud computing [e.g. Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS)] is a new-generation service-oriented technology to support multiple companies to deploy and manage services for accessing and exploiting over the Internet. Cloud computing for manufacturing would provide a cost-effective, flexible and scalable solution to SMEs by sharing complex manufacturing software with lower support and maintenance costs. The development of Cloud manufacturing includes four layers: (1) Manufacturing resource layer, such as manufacturing equipment, sensors, servers, etc.; (2) Manufacturing virtual service layer, in which manufacturing resources are identified, virtualized and packaged as services. Identification and communication technologies have been researched, including wireless sensor network, Internet of Things, MTConnect [96], etc.; (3) Global service layer, which relies on a suite of Cloud computing technologies such as PaaS to take global service computing and supporting for various demands and requirements; and (4) Application layer, which is the interface for users to invoke services for applications.

Recently, several research projects have been funded by the EU FP7 to investigate important research issues and applications of Cloud manufacturing. The project ManuCloud is to develop Cloud-based infrastructure to provide better support for on-demand manufacturing supply chains in the photovoltaic, organic lighting and automotive industries [97]. The project GloNet is aimed at implementing PaaS/SaaS-offering solutions to facilitate SMEs to cooperate with global supply chains and customers to develop highly-customized products. The project ExtremeFactories proposes the conception of a collaborative Internet-based platform with semantic capabilities in globally acting networked SMEs. However, there are no any projects to develop Cloud-based smart services for sustainable and adaptive manufacturing decision making, which is an imperative research area for developing a comprehensive Cloud manufacturing environment.

10.5 Future Research Opportunities for DCE

DCE has been an active R&D area for about two decades. Some manufacturing and engineering companies have partially implemented in-house collaborative design systems. We expect a great future for DCE and envision future collaborative product development systems as being:

- fully integrated with all necessary software tools connected through the network covering the full product lifecycle from conceptual design, to detailed design (with detailed modeling, simulation and optimization), virtual prototyping, manufacturing, service and maintenance, and final disposal;
- integrated with physical testing and validation systems for "hardware-in-the-loop" simulations during the new product development;
- implemented as semi-automated interactive systems that involve human interventions;
- operated on a Cloud computing environment with automated computing load balancing, quick access and fast transfer of large volumes of engineering data;
- secured with sophisticated security and privacy protection mechanisms;
- able to allow users to choose favorite software tools according to their experience and preference;
- able to provide different users (including engineers and managers, sales and services staff, as well as customers and suppliers) with different access privileges to the same product data/information.

To achieve this vision, a number of challenging issues have been identified for the academic research, further development, and wider deployment of collaborative design systems in industry. In fact, these challenges are also opportunities for the related research community. Among others, the following areas are believed to be future research opportunities and challenges:

- Ontology and Semantics Based Integration: One of the most difficult tasks in collaborative product design is to agree on the ontological commitments that enable knowledge-level communication among the distributed design parties. Another difficulty is the integration of the various available design tools. If the tool data and models are encapsulated, rather than using a standardized and unified approach, each tool will be free to use the most appropriate internal representations and models for its intended tasks. This is not a new research topic, but the progress in this area has not been satisfactory. The emergence of Semantic Web makes it promising;
- Interoperability among Product Models: Models help designers understand the nature of a design process by ignoring some of the not-so-important details. When deciding how to model a design process, determining the appropriate levels of abstraction is very critical for the model to be beneficial to its users. A key issue in collaborative design from a designer's perspective is how to bridge the multi-facet models required supporting a complex design project at various stages of the design process. The challenge is to use the relevant model

for each task (the right abstraction and granularity) and to communicate the results in a suitable form to the various parties involved, whose needs are different and interests are diverse. One way to address this issue is through Collaborative Design Process Modeling which has been an active research topic recently, but significant efforts are still required;

- Product-Centric Design Methodology: A product-centric design methodology is considered as a suitable approach for the distributed collaborative product design. Featured by its self-learning ability, product-centric design fits well in a dynamically changing environment. Modeling, collaboration, design and development issues in the whole product life cycle need to be comprehensively taken care of. Fundamental research is still required in this area;
- Data/Information/Knowledge Management: Challenges in this area include knowledge discovery, support for natural language processing and information retrieval, capturing of design intent in multimedia formats, dynamic knowledge management, self-learning, reasoning and knowledge reuse. Based on the current Web infrastructure, users are allowed to access server resources primarily through HTTP and FTP. Using appropriate protocols to access right data at right locations is essential in collaborative product development environments. This feature is particularly useful in large collaborative product design and engineering projects where access to large volumes of data at different locations is frequent;
- Collaborative Intelligent User Interfaces: Human involvement in collaborative engineering design processes is highly expected. Designers need to interact with a design system and negotiate with peers via a user interface. The challenge is to make intelligent interfaces available to all resources so that the designers will have more flexibility to do efficient and effective design. The interfaces should be integrated, expressive, goal oriented, cooperative, ease of use, and customizable;
- Distributed Design Project Management: There must be some ways of managing all the resources involved, including people, organizations, software tools, and equipment. Relevant research issues are collaborative workflow, conflict management, cost and task management, activity scheduling, and computing resource management. In an interesting experimental work, Hammond et al. [98] used a socio-technical theory as a framework to explore differences in engineering design team decision making as a function of various media of communication. Their results indicate that design teams communicating via an electronic medium perceive an increase in mental workload and interact less frequently, but for a greater total amount of time. These results brought interesting implications and suggestions for the management of distributed design teams;
- Drag and Drop Functionality: Drag and Drop is a highly desired function in collaborative design using multiple computational tools. For example, a part designed under a CAD system may be moved to a CAE tool's graphical interface for analysis and simulation, and to a DFM tool's graphical interface for

manufacturability analysis, and so on. It becomes more convenient if there is a drag and drop function that can copy or move a graphical object from one CAD/ CAE system to another, particularly in a Web-based collaborative design environment. In fact, it is a type of communication between the two systems through the moving graphical object. The challenge is therefore to develop a common model or language for these related systems. A significant amount of research is needed to determine standard geometric representations for features that can be used by different CAD and simulation tools. It also requires research and development of drag and drop type standards similar to OLE (Object Linking and Embedding) which provides a protocol for organizing data in a standard format for exchange between different systems;

- Security and Privacy: With the implementation and deployment of DCE applications in industry, security and privacy issues become more and more important. The number of papers on this topic submitted to CSCWD conferences [99] has increased significantly during the past few years. This will continue, particularly with more practical techniques and applications;
- Software Self-Management and Self-Healing: Since software self-management and self-healing have become an active research area, it would be nature to extend the research into DCE systems;
- Social Software and Mass Collaboration: Social software approach and Wiki-style collaboration tools may be developed and used for knowledge-intensive collaborative design systems [100, 101];
- Cultural and Social Issues: With the globalization of manufacturing industry and the development of worldwide production consortia, a special attention is required with respect to cultural problems. Future collaborative design systems will need to integrate results from human sciences in order to address the cultural difference of designers and product users;
- New feature-based formats and enhanced streaming technology for Web applications: The primary geometric data in a VRML model are triangular patches and boundary trimming lines between faces, and the information for the high-level features cannot be preserved. In order to organize the visualization data as a feature-based format to support some feature-based manipulations in the Web-based visualization module, such as highlighting or hiding a feature in a part, dynamically retrieving some important parameters and attributes of a feature, or evaluating the creation history of the part, a new visualization format based on features and VRML needs to be developed. For the 3D streaming technology, such as Hoops streaming toolkit™ and the RealityWave vizStream™, not all components or details of the entire component might be required for viewing at each instant, and different users might have interests in different portions of a model. The 3D streaming technology should be enhanced to provide the selective visualization function and adaptive multi-resolution representation according to users' definitions and requirements.

10.6 Concluding Remarks

DCE has been recognized not only by the academic research community but also by the industry as a way to address the requirements resulted from the increasingly complex product development and high customer expectation. With the significant development and advancement of Internet and Web based technologies during the past two decades, DCE has progressed dramatically. To achieve its full potential and the vision of fully integrated collaborative product development systems, significant R&D efforts are still required. Some research challenges discussed in this chapter may be addressed within next few years, while some of them may need a few decades to be well addressed.

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Chapter 11
Manufacturing Paradigm Shift Towards Better Cloud Computing in the Military Environment: A New Model for Collaboration in the Operational Information Exchange Networks

Michele Tutino and Jörn Mehnen

Abstract Today's budgets are tighter than those at any time in recent history. However, despite severe budget constraints, military demands for highly dynamic federated mission are still increasing especially toward Information Technology (IT). This introduces new challenges for organizations. They are moving from a device-centric view of IT toward a view that is application, people, and information centric. Military organizations are not excluded from this new process which is the fundament of a new theory called Network Enabled Capability (NEC). In addition, the requirements of timeliness, accuracy, ubiquity, assurance and security, rapid exchange of information in the battlefield across all pieces and organizations are the leverage to accomplish the military mission and fundamental for the command and control process also defined with the Observe, Orient, Decide, Act cycle (OODA). Cloud Computing aligns, on one hand, with this new world view and challenges, as the existing infrastructures can be used more efficiently and expanded quicker and leverage the implementation of NEC in the military operations where concepts like information assurance, information sharing, flexibility and scalability are getting more and more important. On the other hand it raises new threats and issues such as the erosion of trust boundaries, ubiquitous connectivity, the amorphous nature of information interchange, the ineffectiveness of traditional static security controls, and the dynamic nature of Cloud services. All this requires new thinking and a new knowledge management approach. However, the new service models, operational models and new technology employed to enable the implementation of Cloud Computing may present

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different risks and additional requirements to the organization. Especially military specific requirements and priorities need to be considered when moving towards tactical Collaborative Cloud. The information exchange requirements in the military operation/mission are growing and getting more complex. In addition security mechanisms and processes often hamper the mission to keep pace with the environmental conditions. Methods such as Reach Back or Home Base clarify that also the military perimeter has changed and modern Command, Control and Information System (CCIS) are best practice for Cloud Computing. This chapter will describe the landscape of Cloud Computing and will focus the view on the possibility of implementing this new concept in the military world. The strengths and the weakness that the implementation of Cloud Computing can introduce in the military operations will be highlighted. In addition, an analysis on what Cloud Computing introduces in the NEC is presented as a starting point for future and more specific studies.

11.1 Introduction

Military organizations are not cut off from the new paradigm of Cloud Computing and the challenges and opportunities that this new IT concept introduces in the means of viewing and accessing computational resources. Being a new concept, there is not a clear understanding of the opportunities present in Cloud Computing along with knowledge about limitations and challenges in implementing this new concept in a military environment.

Like any new paradigm, Cloud Computing opens new scenarios. This is particularly important in the military environment where collaboration, agility, scalability and availability are the main requirements to run a military operation/mission. The Cloud could be the solution to enhance them as well as it provides the potential for costs reduction through optimized and efficient computing infrastructures.

However, in complex organizations such as the Armed Forces, this new approach raise also concerns: the erosion of trust boundaries or re-perimeter are accelerated; ineffectiveness of traditional static security controls because of the ubiquitous connectivity and amorphous nature of information exchange; new Service Level Management; new way of thinking in the approach of security measures and information process capabilities [1].

This chapter provides an overview of the new scenario that the Cloud Computing paradigm has opened in the military environment and how the information technology, processes and procedures have changed as a consequence of implementing a Cloud solution in military IT infrastructures. The main intent is to describe the most relevant aspects that Cloud Computing has in the Net Enable Capability transformation process which the most advanced Armed Forces are still facing and is shifting the battlefield on another dimension: the information.

Of course, the complexity of Cloud Computing does not allow a comprehensive and detailed analysis of the subject in this chapter; here a brief overview of the most relevant aspects of the Cloud implementation and the main enhancements, issues and capability improvement which Cloud brings in military activities or operations is presented.

11.2 Setting the Scene

The military world—like any private or public organization—is influenced by the development of modern information technology and services. The main interests on the base of information technology enhancement is to be able to communicate (exchange information) at every place, at every time and with everyone. Cloud Computing gives nowadays the opportunity of breaking the perimeter of a company or organization for becoming global. The de-perimeterization and the erosion of trust boundaries, amplified and accelerated by Cloud Computing, ubiquitous connectivity, the amorphous nature of information interchange introduces new challenges both in the common information infrastructure and in the approach of information assurance. In addition global collaboration and decision making within seconds hampered by purely technology driven IT-security solutions does not meet any longer the requests, whether in global business nor in military operations.

Security controls in Cloud Computing are not more different, for the most part, than security controls in any IT environment from functional management perspective. The Security Management Infrastructure (SMI) approach of NATO and EU [2, 3], and Nations such as USA [4] or the UK [5], and security management capabilities like Identity Management, Privilege Management, Metadata Management, may be adopted for Cloud usage easily [6].

However, Cloud Computing may present different risks and additional requirements to an organization compared to a traditional IT solution because of the service/operational model employed and technologies used to enable Cloud services. Moving sensitive data and applications to an emerging infrastructure require double checking of regulation and security policies, particularly for military considering the peculiarity of information in operational fields [1]. Security management goals can be defined only if the architecture, including components and characteristics that constitute the overall system such as the technology, processes, services, and human capital is understood well. Especially military specific requirements and priorities need to be considered when moving toward a strategic or tactical Collaborative Cloud [7].

Three examples clearly showing how the Internet and its global availability is requiring a new way of thinking of information management and systems for military side are: first, the Network Enable Capability (NEC) implementation, it is a theory of war in the information age that seek to translate an information advantage into a competitive war fighting advantage. The power of NEC is derived from the effective linking or networking of knowledgeable entities that are geographically or hierarchically dispersed and from the rich information and data environment where military forces and mission partners must have rapid access confident of finding relevant, accurate and timely information; second, the growing US and Afghanistan Coalition military use of Information Surveillance and Reconnaissance (ISR) aircrafts that is overloading the ability of processing centers to handle the deluge of information gathered from manned and unmanned aircrafts carrying more sensors and with persistent wide area airborne surveillance (WAAS) capabilities [8]; third, the evolution of Command and Control (C2) computer Information Technology systems from their inception as essential electronic "maps" displaying geographical position of known "friendly", "unfriendly", and "unknown" units and platform ("tracks") for a specific purpose (e.g., "surface", "ground", "air" plot) to complex systems integrating into this electronic map; logistics, intelligence, planning and other sorts of geospatial data gathered from sensors becoming more and more numerous [9].

The use of new technologies and techniques, mainly driven from Internet accessibility and diffusion, has allowed people take greater profit from information, to attain greater information superiority, and cooperation. Inspired by that, military "business" is looking at those new technologies and techniques to improve and transform its way of doing business and realize full benefits such as: ubiquity, trust, teaming and cost-effectiveness.

11.3 Cloud Computing

11.3.1 Background

There are many definitions of Cloud Computing, but most of them focus on just certain aspects of the technology [10, 11] and according to [12] the largest consent amongst the authors who have defined Cloud Computing is spanning around the future service, hardware, software, scalability and Internet/network and usage-bound payment models and virtualization are mentioned as well [12]. The National Institute of Standards and Technology [13] and the Cloud Security Alliance [1] give a baseline definition of Cloud Computing. They both define Cloud Computing as a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. A definition that regards the concept holistically, from both the application and infrastructure perspective, focusing on the deployment of computing resources and application rather than on a technical description is [12]:

> Cloud computing is an IT deployment model, based on virtualization, where resources, in terms of infrastructure, applications and data are deployed via the Internet as a distributed service by one or several service providers. These services are scalable on demand and can be priced on a pay-per-use basis.

A better overview of the Cloud Computing model is given by the following tables where the Cloud model can be thought of as being composed of three service models (Table 11.1), four deployment models (Table 11.2) and five essentials characteristics (Table 11.3) [13]. Overall risks and benefits will differ per model and it is important to consider both of them when implementing the Cloud model in an enterprise or legacy environment [14].

Next to the three main service models various subtypes exist that can be summarized as "XaaS" (Fig. 11.1). Referring to the deployment models, it might be said that there is not a clear boundary between "private" and "public" Cloud infrastructure, making it difficult to assign real-life environments to one or another category [15]. Typically a wide variety of sub forms or hybrid constellation like Community, Federated or Partner Clouds, can be observed. They can be summarized as "Collaborative Clouds" and provide the most effective scenario for highly dynamic future military missions both in operations and in routine activities. They allow IT managers to flexibly distribute their applications load to internal or external resources with the opportunity to change their decision quickly and easily in case the business needs or goals evolve.

Table 11.1 Cloud computing service models

Cloud computing service models		
Service model	Definition	To be considered
Infrastructure as a service (IaaS)	Capability to provision processing, storage, networks and other fundamental computing resources, offering the customer the ability to deploy and run arbitrary software, which can include operating systems and applications. IaaS puts these IT operations into the hands of a third party.	Options to minimize the impact if the Cloud provider has a service interruption
Platform as a service (PaaS)	Capability to deploy onto the Cloud infrastructure customer-created or acquired applications created using programming languages and tools supported by the provider	Availability Confidentiality Privacy and legal liability in the event of a security breach (as databases housing sensitive information will now be hosted offsite) Data ownership Concerns around e-discovery
Software as a service (SaaS)	Capability to use the provider's applications running on cloud infrastructure. The applications are accessible from various client devices through a thin client interface such as a web browser (e.g., web-based e-mail)	Who owns the applications? Where do the applications reside?

Table 11.2 Cloud computing deployment models

Cloud computing deployment models		
Deployment model	Description of cloud Infrastructure	To be considered
Private cloud	Operated solely for an organization May be managed by the organization or a third party May exist on-premise or off-premise	Cloud services with minimum risk May not provide the scalability and agility of public cloud services
Community cloud	Shared by several organizations Supports a specific community that has shared mission or interest. May be managed by the organizations or a third party May reside on-premise or off-premise	Same as private cloud, plus: Data may be stored with the data of competitors
Public cloud	Made available to the general public or a large industry group Owned by an organization selling cloud services Typically accessed via the internet	Same as community cloud, plus: Data may be stored in unknown locations and may not be easily retrievable Connection bandwidth availability/capability
Hybrid cloud	A composition of two or more clouds (private, community or public) that remain unique entities but are bound together by standardized or proprietary technology that enables data and application portability (e.g., cloud bursting for load balancing between clouds)	Aggregate risk of merging different deployment models Classification and labeling of data will be beneficial to the security manager to ensure that data are assigned to the correct cloud type

11.3.2 Enterprise Services (Web 2.0)

Enterprise services (also social media) provide features or functionalities for collaboration abilities, on the World Wide Web, not only in a civil or commercial but more and more in the military environment. Those functionalities which facilitate interactive information sharing, interoperability, user-centred design in the Web are typical realization of the Cloud services. Example of Web 2.0 include web-based communities, hosted services, web applications, social-networking sites, video sharing sites, wikis, blogs, mashups and folksonomies. Generally Web 2.0 sites allow the users to interact with other users or to change website contents, in contrast to non-interactive sites where the users are limited to the passive view of the contents provided; to run software and applications entirely through a browser; to own the data on a Web 2.0 site and exercise the control over that data. In web development, a mashup is a web page or application that uses and combines data, presentation or functionality from two or more sources to create new services.

Table 11.3 Cloud computing essential characteristics

Cloud computing essential characteristics	
Characteristic	Definition
On-demand self-service	The Cloud provider should have the ability to automatically provision computing capabilities, such as server and network storage, as needed without requiring human interaction with each service's provider
Broad network access	According to NIST [13], the Cloud network should be accessible anywhere, by almost any device (e.g., smart phone, laptop, mobile devices, PDA)
Resource pooling	The provider's computing resources are pooled to serve multiple customers using a multitenant model, with different physical and virtual resources dynamically assigned and reassigned according to demand. There is a sense of location independence. The customer generally has no control or knowledge over the exact location of the provided resources. However, he/she may be able to specify location at a higher level of abstraction (e.g., country, region or data centre). Examples of resources include storage, processing, memory, network bandwidth and virtual machines
Rapid elasticity	Capabilities can be rapidly and elastically provisioned, in many cases automatically, to scale out quickly and rapidly released to scale in quickly. To the customer, the capabilities available for provisioning often appear to be unlimited and can be purchased in any quantity at any time
Measured service	Cloud systems automatically control and optimize resource use by leveraging a metering capability (e.g., storage, processing, bandwidth and active user accounts). Resource usage can be monitored, controlled and reported, providing transparency for both the provider and customer of the utilized service

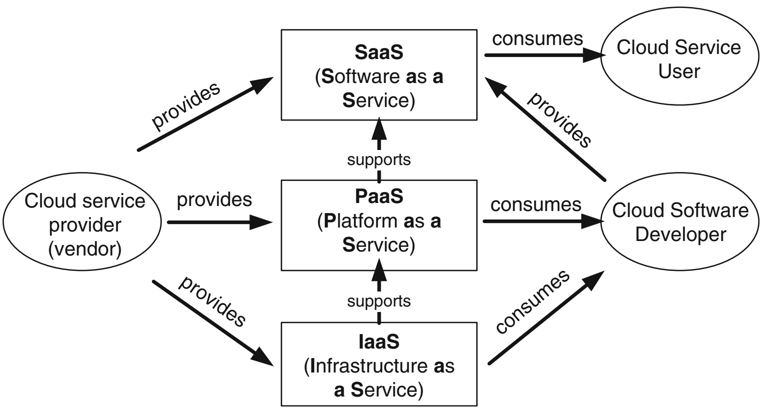

Fig. 11.1 Cloud computing service models subtypes [7]

Web 2.0 websites typically include the following features and techniques referred to as SLATES (European Defence Agency 2010):

- Search: Finding information through keyword search.
- Links: Guides to other related information.
- Authoring: The ability to create and update content leads to the collaborative work of many rather than just a few web authors. In wikis, users may extend, undo and redo each other's work. In blogs, posts and the comments of individuals build up over time.
- Tags: Categorization of content by users adding one-word descriptions to facilitate searching, without dependence on pre-made categories. This is referred to as "folksonomy".
- Extensions: Software that makes the Web an application platform as well as a document server.
- Signals: The use of syndication technology such as Really Simple Syndication but sometimes Rich Site Summary (RSS) to notify users of content changes.

The fast-growing community of web users, relayed by the explosion of the functionalities and applications typical of the Web 2.0, and contemporary associated to the spread of modern smart mobile phones, has provided innovative commercial-off-the-shelf (cots) solutions to augment military-grade information systems with user-oriented, flexible and open solutions born in the commercial world [16]. These new collaborative tools and info-systems have formed a new category of core services in the military environment, shared by business-oriented networked communities. Some example are the HTML and XML formats getting more and more a standard used to build applications, with web application service vastly expanding their potential for economic information exchanges over constrained network. Although limited by nature in terms of evolution of content, these militarized XML formats are investigated to bridge interoperability gaps between soldier-level information exchanges and higher command echelon [16] and of course, the Cloud seems the most "fruitful soil" where to make these information capabilities expand and grow luxuriant.

As a consequence of expansion of Web 2.0 applications and of militaries over the world are populated with younger, the main users of social networks, the development of user-defined service is reverting the relationship between technology offering and military requirements [16]. Furthermore, the spread of modern smartphones, which are based on microprocessor with a capacity that is only a shade under that of a personal computer, and considered one of the causes of such a success of social networks, provide a platform that can be used for an infinite number of purposes [17]. Some examples are the gameboy-type controls used to fly drones, development of non-combat Apps in smartphone jargon, or the building up of communications infrastructure that would involve army-issued smartphones, to support the personnel selection. Although this fast growth of commercial practises of social networks had heretofore been seen as a distraction from the soldier's core mission: persistent ability to seize and control ground; nowadays, these new tools often enable military solution providers to focus on their core trade delivering robust resilient and mission-focused information superiority solutions [16], the last considered the strategic factor in modern warfare and security missions.

11.4 Cloud Computing Collaboration

Next to our own military forces, modern stabilizing missions or military operations/exercises include external partners (e.g., armed forces or police of the host nation, nongovernmental organizations such as humanitarian groups, which permanently or temporally support the mission, the press, or commercial IT providers) which help accomplishing the mission goal and are allowed to use specified resources of the own infrastructures with a strong focus on collaboration between applications and software and facilitation of reusing and integrating data between them.

A typical scenario is shown in Fig. 11.2. It shows the communication and information infrastructure of nations or public organizations [18], which collaborate according to mutually agreed data and information exchange, information mission support and security policies. The overall Cloud infrastructure can be built upon this existing IT infrastructure using open source or legacy software and each organization incorporates its resources in their private Cloud infrastructure. The Cloud services can be used by individuals (e.g., the members of Branch A2 within Nation A, members of other nations or external users), and can be of any type (SaaS, Paas or IaaS) [19].

Following the description of Fig. 11.2 by Kretzschmar [19], a Private Cloud of a Nation A may contain several Clouds itself [e.g., Cloud of a branch of Department of Defense (DoD), battle unit, command and control headquarter, etc.] to comprise these Clouds as one transparent Private Cloud to authorized users. Especially Clouds based on highly mobile elements such as ships, fleets, mobile command posts, etc. that can ad-hoc offer Cloud Services can be part of the private Cloud of Nation A. The included Clouds of Nation A can be deployed at different

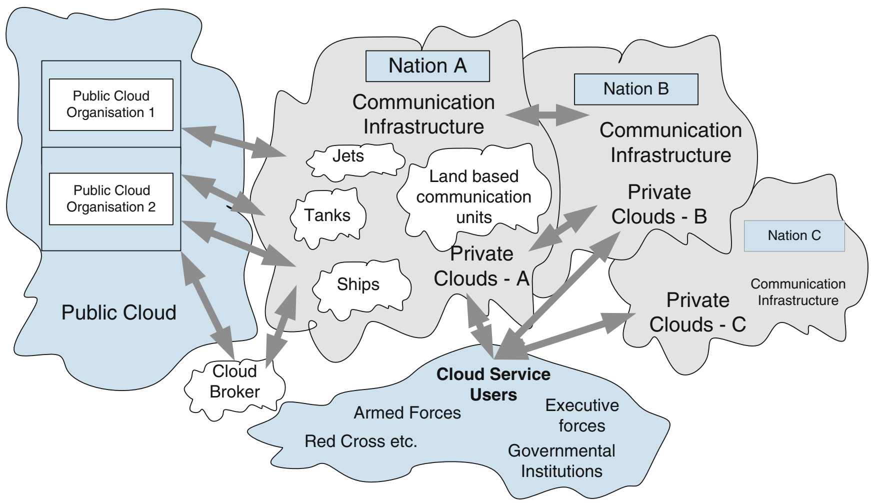

Fig. 11.2 Typical Cloud within a joint task force (modified from [19])

geographic locations and organizational branches, subsidiaries and units spread on the battlefield and can be seen as a collaborative Cloud, even when it is assumed as a private Cloud from the perspective of Nation A [19]. Furthermore, a private Cloud Service from Nation A is not strictly "private" or being considered a close system but consist of several Cloud Services from partners or a public Cloud Service provider (a federated system) where Cloud Service is provided by one or multiple organizations.

Commanders can make intelligent and flexible decisions about what parts of their application loads they want to run internally and what parts externally (consider national security policies that many time do not allow a complete information exchange and hamper collaboration between operations partners)—and then have the ability to change their minds quickly and easily as the mission goals and requirements may evolve or change. As a rule of thumb, compute intense Cloud services better be provided and used by Public Cloud providers, but as dynamic security policies may define another risk for the transferred data and technical limitation such as bandwidth availability (think at operations in area with a lack of communication technology development) the compute Cloud service will be moved and deployed in back to the private Cloud [19]. Additional processor or compute resources can be acquired from public Cloud providers in burst situations (e.g., compute intensive operations research tasks) or outage of own infrastructure [7].

As shown in the above scenario, if on the one hand the Cloud introduces a new paradigm in the "Information Battle Space" allowing information exchange and collaboration more flexible, efficient, faster and cheaper, on the other hand breaking the "perimeter" it introduces new risks and new threats which require a new security information management approach. When we use the Cloud, one probably may not know exactly where the information is hosted and in addition, information in the Cloud is typically in a shared environment alongside data from other customers. The use of standardized and non-proprietary protocols to communicate and exchange information is paramount to prevent risks of vendor lock-in because in public Cloud there is not a particular focus on collaboration between application and facilitation of reusing data between them [20].

Management information flow in a collaborative multi-tier Cloud-based infrastructure happens not only horizontally between different Clouds but also vertically between Cloud security management and the overarching security management on organization level and "diagonally" between Clouds, which collaboratively provide complex value added services [7]. In this type of multi-tier service provider arrangement risks of security issues are shared from each party because every single risk impacts all parties at all layers over the complete security.

From all of this it follows that to achieve the integration of system in a collaborative Cloud infrastructure, the adoption of a standard-based system design and implementation to enable interoperability, facilitate federated security management operations, allow the use of commercial products and ease evolution of information systems, is necessary.

11.5 Cloud Computing in the Net-Centric Warfare

The concept of Network Centric Warfare (NCW) is a doctrine introduced to the U.S. Department of Defense (DoD) by Vice Admiral D. A. Cebrowsky and J. Gartska in a series of articles and books beginning in the late 1990s [21, 22]. Now commonly referred to as Network Centric Operation (NCO), it is a new military doctrine or theory of war in the information age that seeks to translate an information advantage, enabled in part by information technology, into a competitive war fighting advantage through the robust networking of well informed and geographically dispersed forces allowing new forms of organizational behavior [2].

As stated by Gen. Camporini (Italy Chief of Defense General Staff) during the "NATO Network Enabled Capability" conference 7 Ed., Rome, 23–25 March 2010—"The NEC concept represents the necessary vehicle to enhance effects in military operations. It represents the key enabler element for the operational community as it can support the collection, fusion, analysis and sharing of information in a seamless and robust way".

The exponential expansion of Communication and Information Systems (CIS) getting more global and available from everywhere; the diffusion of Twitter™, Google™, Facebook™, stock exchange tools and the so called "web services" which bring users closer together and allows collaboration within the virtual world, bringing more benefits to the users through collaboration and information sharing; the IT tools are becoming more and more mobile, smaller, smarter, and provide the users with the capability to hook into a network of information whenever they need and wherever they are; all this provide by default Network Enable Capability in the CIS domains.

The implementation of NEC leads to the following achievement in a military operation and mission according to EU NEC Vision Report [2]:

- Better Knowledge: through easy and complete information sharing;
- Faster Decisions: through high speed networks, sense and respond mechanisms;
- Improved Awareness: through permanent connectivity, publication for users and web engines.

Furthermore, within a NEC environment the average military achieves more output, receives more accurate information and is capable of making the right choice and taking the right action, in his mission task or job competence. At organizational and decision level military forces and mission partners have rapid access to relevant, accurate and timely information; improved ability to create and share the knowledge required to make superior decision amid tremendous quantities of operational data gathered from diverse sensors, operational units and service-oriented information systems.

In synthesis, the following activities in military operations are improved from the NEC implementation and a number of benefits can be realized: planning; monitoring; command and control (C2); situation awareness; consultation, briefing and decision support; workflow supporting staff activities. The main advantage introduced is to reduce the constraints on users by freeing the users from operational constrains like space, time and expertise. Of course, NEC implementation brings some vulnerabilities and difficulties like an over dependency on information; potential exposure to cyber-attacks; increased complexity; integrating legacy bespoke systems; judicial and administrative difficulties; etc.

In order to create such an integration of information systems which in the future can be envisioned as a federation of multiple national and trans-national, public and private enterprises where people, information and technology seamlessly operate together, it requires a rethinking of how data, applications and services, and their supporting infrastructures and security are provided and managed. Furthermore, it requires an up-to-date perspective and approach to support for applications, data, and services in the NEC environment, envisioned as the enterprise of enterprises able to provide a continuum with which, governmental, military and civilian in an operational coalition enterprises can operate as a team, each bringing their own skill and capabilities for the mutual benefits to be realized.

This continuum in the computing environment, as a result of the current evolving of technology can be easily identified in the "Cloud". Undoubtedly, Cloud computing is one of the inspiring elements of the NEC vision together with World Wide Web (W3) and Service Oriented Architecture (SOA) which have affected the way individuals and organizations conduct business, private and social activities. In the civilian domain this changes is named Effective Business (responsive, variable, resilient and focused). In the military domain, applying those changes is covered by Revolution in Military affairs or Battle Space Transformation [2].

As the commercial Internet goes to a Cloud Computing model to support advanced applications and services for commerce and operations of industry, Armed Forces should leverage those advantages as much as possible to improve both strategic and tactical operational capabilities and to fully implement the NEC concept. One example of effective exploitation of Cloud computing in military operation comes from the use of Information Surveillance Reconnaissance (ISR) aircrafts in Afghanistan. The Unmanned Air Vehicle (UAV) aircraft and sensors capabilities have improved in the last few years allowing them longer flight endurance, a persistent wide area airborne surveillance as well as carrying more antennas, sensors and full motion video cameras. Legacy ground information systems cannot keep pace with the deluge of the incoming data flow and the new glut of surveillance data threat to create a bottleneck at the processing centre on the ground. Furthermore, so much data streaming in from all those sensors create a gap in the ability of the distributed common ground systems to sort through all the data and distribute it to those who need it [8]. The impasse has been solved by Kevin Meiners (U.S. Assistant Deputy for the Undersecretary of Defense for Intelligence, 2008) who was calling on defense contractors to provide intelligence centers with Cloud computing applications [8].

11.6 Conclusions

IT innovation in the last few years is getting faster and faster thanks to the development of mobile devices, the diffusion of internet and the cheaper processors. Cloud Computing is the main result and core enabler of this transformation. Just as every organizations which benefit from this new technology, Armed Force of the most advanced nations cannot ignore the advantages that Cloud Computing could bring in their "business" or better "military affairs". Collaboration, information and data sharing, data integration, costs reduction, agility and flexibility within a coalition in the military operations can be exponentially improved by the Cloud implementation although the information becoming more amorphous on the "battlefield", can raise more or different risks compared with legacy systems, which might be better studied and investigated.

Cloud Computing will enable to accommodate the demands of net-centric concepts and shift the battlefield more and more from a physical level to a digitalized and info-centric dimension. Cloud applications open a new promising scenario by improving the net-centric military warfigthing capabilities and allowing users to access to information at every time and at every spot. Although, this raises both opportunities and risks it is necessary to be good "entrepreneurs" or—quoting Machiavelli—"… simply those who understand that there is a little difference between obstacle and opportunity are able to turn both to their advantage".

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