CRANFIELD UNIVERSITY

Wei Han

Modelling for data management & exchange in Concurrent Engineering - A case study of civil aircraft assembly line

School of Applied Sciences

MSc by Research Thesis
Academic Year: 2012–2013

Supervisor: Dr Ip-Shing Fan
November 2013

CRANFIELD UNIVERSITY

School of Applied Sciences

MSc by Research Thesis

Academic Year: 2012 –2013

Wei Han

Modelling for data management & exchange in Concurrent Engineering - A case study of civil aircraft assembly line development process

Supervisor: Dr Ip-Shing Fan
November 2013

This thesis is submitted in partial fulfilment of the requirements for the degree of Master of Sciences

ABSTRACT

This research aims to improve the dataflow performance of the Concurrent Engineering (CE) practice in the detail design stage of the aircraft Assembly Line (AL) in the C919 aircraft project. As the final integrator of the aircraft, Shanghai Aircraft Manufacturing Company Ltd. (SAMC) is responsible for developing the AL with global suppliers. Although CE has been implemented in AL projects to shorten lead time, reduce development cost and improve design quality, the lack of experience and insufficient infrastructure may lead to many challenges in cooperation with distributed suppliers, especially regarding data management/exchange and workflow control. In this research, the particular CE environment and activities in SAMC AL projects were investigated. By assessing the CE performance and benchmarking, the improvement opportunities are identified, and then an activity-oriented workflow and dataflow model is established by decomposing the work process to detail levels. Based on this model, a Product Data Management (PDM) based support platform is proposed to facilitate data management/exchange in dynamic workflow to improve work efficiency and interoperability. This solution is mocked-up on the Siemens Teamcenter 8.1 PLM(Product Lifecycle Management) software and its feasibility is checked. The mock-up is evaluated by SAMC experts and suppliers. The feedback shows the acceptance of the model by experts and the urgency of improving data/work flow design before PLM implementing.

The result of this research is useful for enterprises in similar environments transiting from pre-PLM to implementing PLM and who wanting to strengthen CE in the new product development.

Keywords: Concurrent Engineering, PDM, interoperability, workflow/data flow, aircraft assembly line

ACKNOWLEDGEMENTS

I would like to thank a number of people who provided enormous support in this research work and thesis writting. Firstly, I want to thank my supervisor, Dr Ip-Shing Fan, for his professional guidance and patience throughout the project. His colleagues, Dr Jorn Mehnen, Dr Ahmed Al-Ashaab and Dr Mark Pawlett also provided me with valuable advice. I would also like to show my appreciation of my colleagues in SAMC and people from the assembly line suppliers who helped me to complete the questionnaire despite their busy daily work. I would like to thank Mr Shane Anderson provided CAD models and giving their generous permission to allow me to use their original work for mock-up.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

3D	Three Dimensions
A/C	Aircraft
ACE	Airbus Concurrent Engineering
AL	Assembly Line
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CAM	Computer-Aided Manufacturing
CAPP	Computer-Aided Process Planning
CCB	Change Control Board
CDR	Critical Design Review
CE	Concurrent Engineering
CIM	Computer Integrated Manufacturing
CM	Configuration Management
COMAC	Commercial Aircraft Corporation of China, Ltd
CRISTAL	Cooperating Repositories and an Information System for Tracking Assembly Lifecycles
CSM	Component and Supplier Management
DFM	Design for Manufacturability
DFX	Design for X
DMU	Digital Mock-Up
EBOM	Engineering Bill of Material
ERP	Enterprise Resource Planning
FDR	Final Design Review

FEMA	Failure Mode and Effect Analysis
ICT	Information and Communication Technology
IDP	Integrated Product Development
IDEF	Integration DEFinition
iDMU	Industrial Digital Mock-Up
IP	Intellectual Property
MBOM	Manufacturing Bill of Material
MS	Microsoft
MRP	Manufacturing Resource Planning
OEM	Original Equipment Manufacturer
RAD	Role Activity Diagrams
RID	Role Interactivity Diagrams
PDM	Product Data Management
PDR	Preliminary Design Review
PLM	Product Lifecycle Management
PM	Project Manager
SAMC	Shanghai Aircraft Manufacturing Company Ltd
QFD	Quality Function Deployment
WFM	Workflow Management

1 Introduction

1.1 CE in aerospace industry

Concurrent Engineering (CE) or Parallel Engineering is a systematic product development method designed to ensure that people from different disciplines work together and simultaneously consider and process all relevant factors including customer's requirement, product performance, manufacturability, procurements and schedule in the whole product life cycle. Compared to traditional sequential development strategy, the main advantage of applying CE in product development includes (Pennell and Winner, 1989; Ranky, 1994, p.22; Addo-Tenkorang, 2011):

- Increased productivity
- Higher design quality
- Reduced cost
- Shortened leading time
- Better ability to meet customer's requirement

In the context of globalisation, to develop large scale and complicated products such as civil aircraft, not only different departments in an enterprise, but also numerous distributed suppliers from all over the world are involved, from the initial conceptual phase to production (Shehab, 2013). With partners in the product development process, enormous data is generated and exchanged every day with entangled workflows. Hence, it is crucial to provide an efficient electronic collaborative environment to support CE activities for project success. In collaborative manufacturing, information systems such as CAE/PLM/ERP are deployed and customised to meet different users' requirements of managing data storage/exchange and cross-workflows (McClellan, 2002, Chapter 5).

1.2 C919 program in COMAC & SAMC

COMAC is the acronym of the Commercial Aircraft Corporation of China, Ltd. Its ambitious goal is to build competitive commercial aircraft which can take their place in the global market. Two projects are under development by this corporation, namely ARJ21 and C919. The C919 project targets the development of a 150-seat aircraft that would compete with Boeing and Airbus. It started in 2008 and the maiden flight is due probably in 2015.

Shanghai Aircraft Manufacturing Company Ltd. or SAMC, is the manufacturing centre of COMAC, responsible for the final assembly job and building other components including the fuselage and stabiliser of the C919. A simplified figure illustrates the role and collaboration relationship of SAMC in this project, as below.

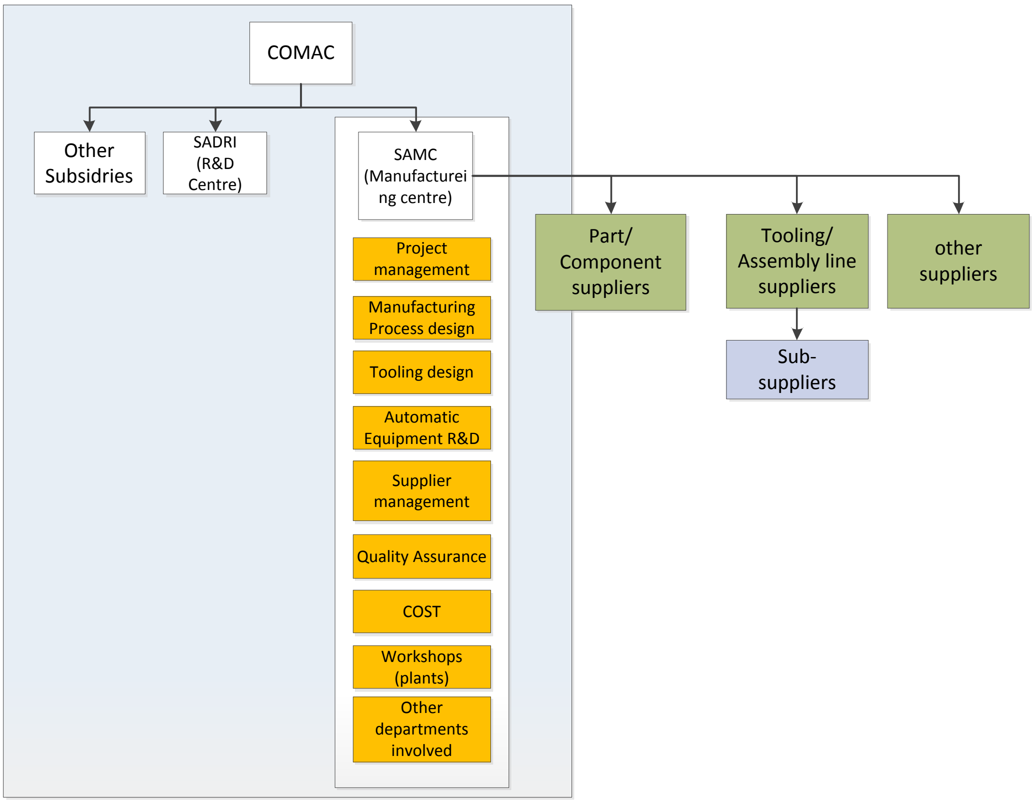


Figure 1-1 The role and cooperation relationship of SAMC in C919 project

A distinguishing feature of the role of SAMC is that it is not only a factory to manage the final assembly work, but it takes the primary responsibility for product realisation. In this case, the extensive work scope includes all relevant collaborative activities with the engineering centre (SADRI) and worldwide suppliers. Therefore, the huge amount of information flows generated in the developing process need to be managed efficiently and effectively. The simultaneous development will finally transfer to synchronic production by joint effort of all the participants.

Besides the main aircraft component suppliers and other system equipment suppliers, SAMC also seeks competent contractors or vendors to build its assembly lines. Integrated specified tooling, sophisticated equipment such as Numerical Control (NC) machine or robot and assembly line are regarded as key manufacturing resources for product fabrication. And assembly line could be regarded as a particular type of complex high value mechanical product. By adopting cutting-edge technology in assembly line, demanding aircraft production rate and quality could be achieved and give the C919 an advantage in the global aviation market.

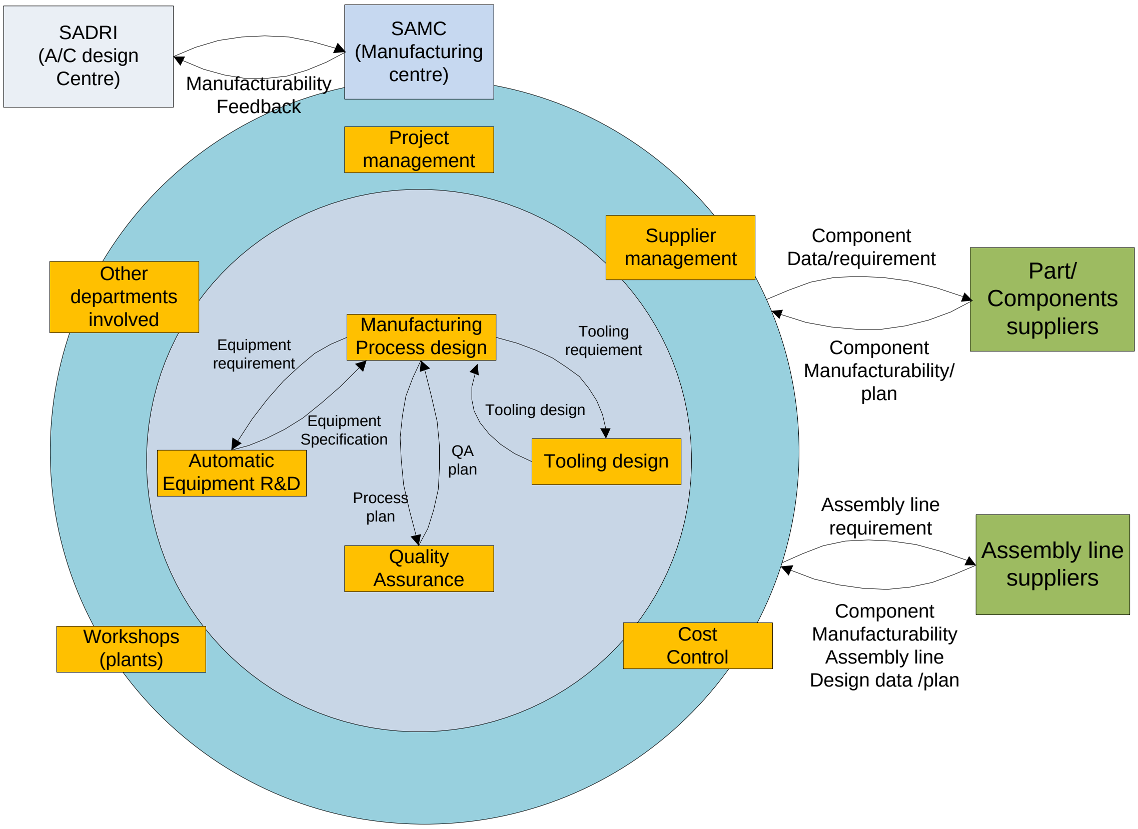


Figure 1-2 The collaborative development of C919 AL in SAMC

The complexity of collaborative work in the assembly line design is shown in Figure 1-2 above. Various internal departments and external co-operators are involved in the iterative development loops.

The author of this research worked for the assembly line project in SAMC for the C919 project between 2010~2012. The expertise is in the domain of airframe assembly and IPT (Integrated Product Team) management. Although the senior leaders of SAMC tried to accelerate the development cycle time by implementing Concurrent Engineering, the author and other key people, including suppliers, were still suffering from challenges including data exchange, data reuse, version management, project scheduling and the collaborative work process did not run smoothly. As pointed out in Section 1.1, to successfully apply CE in complex product development needs strong supportive environment and careful workflow design to support cross-disciplines/organisations collaboration. Without them, the effect of implementing CE in the C919 program will be diminished and expected goals will be unachievable.

1.3 Problem statement and aims

Despite years of effort by SAMC to achieve CE implementation in product development, the experience of AL project shows there is still a significant gap to reach effective collaborative product development. This problem is possibly caused by inadequate data management and exchange, with implicit workflow pattern in distributed product development, consequently weakening in the effect of CE.

This research aims to design an integrated solution for both SAMC and supplier teams to improve concurrent engineering performance by accelerating the data flow and workflow in AL detail design phase.

1.4 Research scope and objectives

This research uses the case of a large manufacturing enterprise which is moving itself from internal collaborative design activities to global cooperation. When elements of CE such as technology, organisation and strategy affect each other reciprocally, a detail industry case allows the investigation of the current work pattern to find improvement opportunities on both workflow/dataflow perspectives. Due to time limitation, only the detail design stage of the SAMC C919 assembly project is studied as a part of whole product design cycle.

The main project objectives are:

1. Investigate and assess the concurrent engineering practice in SAMC assembly line projects to identify improvement opportunities;
2. Propose a suitable solution for infrastructure improvement and CE practice in SAMC;
3. Mock-up the solution on a mainstream commercial software to verify its feasibility;
4. Validate the solution by demonstrating the proposed solution to key people in the AL project in SAMC and evaluate the feedback.

1.5 Thesis structure

Although the research consists of iterative loops within the literature review, AS-IS mapping and solution finding, in this thesis the structure is designed in the conventional sequential way. Hence the first three chapters are the introduction, literature review and methodology. Chapter 4 describes the data collected from SAMC and a flow chart is designed to map the process and data flow. Chapter 5 proposes the workflow and dataflow modelling and presents the mocking-up in the available platform. Validation by means of questionnaire is also included in the chapter. Chapter 6 discusses main findings and feedback from the questionnaire. Chapter 7 provides the conclusion.

2 Literature review

2.1 Literature review structure

The implementation of CE in aircraft assembly line development is the main research objective for this thesis. Therefore the literature search scope covered studies over the last 20 years in the relevant fields. In total, over 70 paper studies and online sources were reviewed, including a number of academic theses. The methodology of how to carry out case studies and create questionnaires was also studied.

The browsing schema and chapter organisation is shown in Figure 2.1.

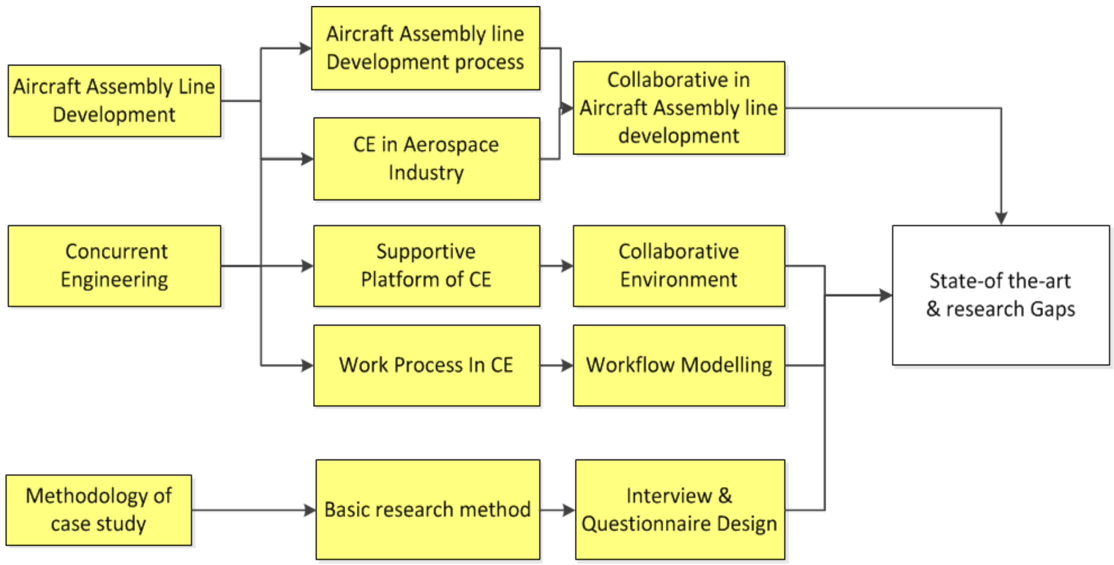


Figure 2-1 The schema of the literature review

2.2 The theoretical foundation of Concurrent Engineering

2.2.1 Product development

Development is an important activity in the product lifecycle. It is a complex process used to convert a concept to product information which normally includes drawing, manufacturing process, cost estimation, service manuals and so on. On average, 80% of the cost of a product is determined during its development (Stark, 2011, p.52).

There are many different Product Development (PD) process models from various industrial practice and viewpoints. One well accepted model is shown in Figure 2.2. Between these phases, a ”*design review*” is normally set to check the result of previous stages and ensure that the next phase can be carried out as planned with appropriate maturity.

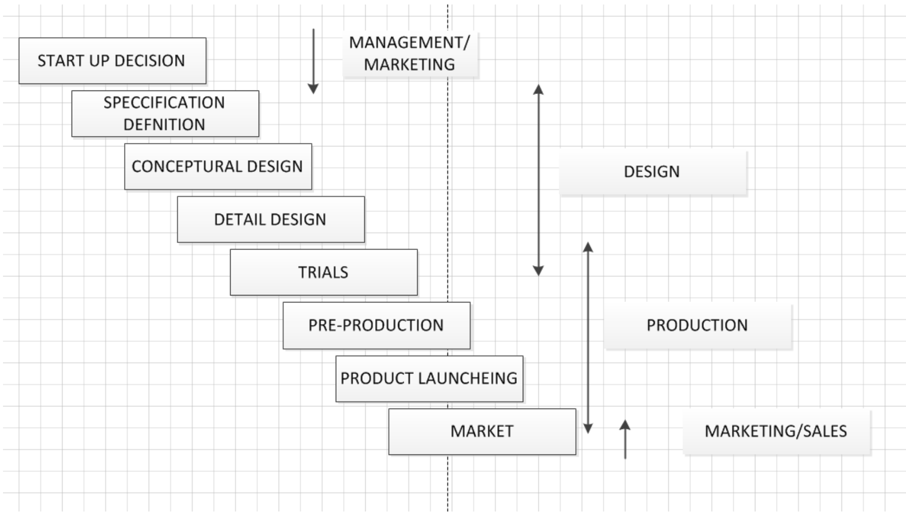


Figure 2-2 The Product development phases (reproduced from Pahl and Beitz 1996, cited by Sorli and Stokic, 2009, p.12)

Following this pattern, the detail design phase is the stage in which the conceptual design is broken down into detail drawings, material specifications and production plans (Sorli and Stokic, 2009, p.11), and the main work in this phase are *Simulation, Improving, Prototyping* (p.87) .

Earl et al (2005, p.183) reviewed the complexity of the product development. They argue that PD is also the process used by the product designer and other disciplines such as production planner and tooling designers to accomplish information in each field under given goals and constraints. Thus unavoidably, people in PD have to face information uncertainties and work together to increase the whole system maturity in iterative loops until stable design and production status can be achieved.

Configuration Management (CM) is very important in product lifecycle. In the standard ANSI/EIA 649(ANSI/EIA, 2001) configuration is defined as:

(1) The product attributes of an existing or planned product, or a combination of products;

(2) One of a series of sequentially created variations of a product.

CM is the process to keep the consistency of more than two aspects in a product lifecycle (ANSI/EIA, 2001). It is regarded as the connection between engineering (design) and the rest of departments in PD (Watts, 2008, p.290).

Fleisher and Liker (1997, p.9) argue that the design of a product is not frozen until it can be successfully fabricated. Changes can happen through the entire range of production phases, and include large scope re-design to minor revision (Eckert et al., p.267). Hence there are three change types in product lifecycle (p.269).

• *product changes;*

• *prototype changes; or*

• *design changes.*

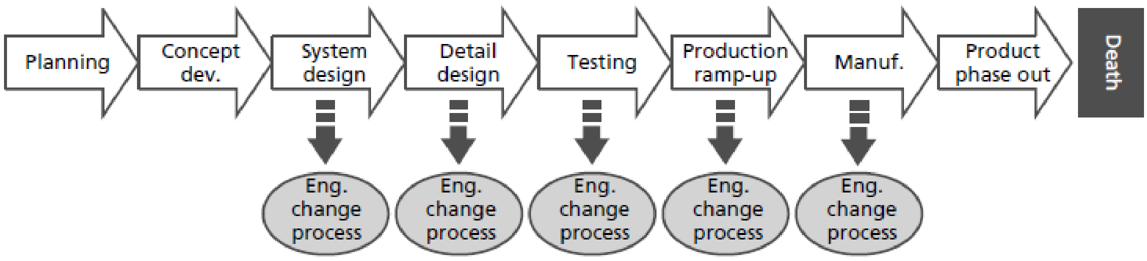


Figure 2-3 The engineering change process in product lifecycle (Eckert et al., 2005, p.268)

An engineering change process pattern is also proposed by Eckert et al.(2005, p.268), which suggests the solution finding loop as in Figure 2-4.

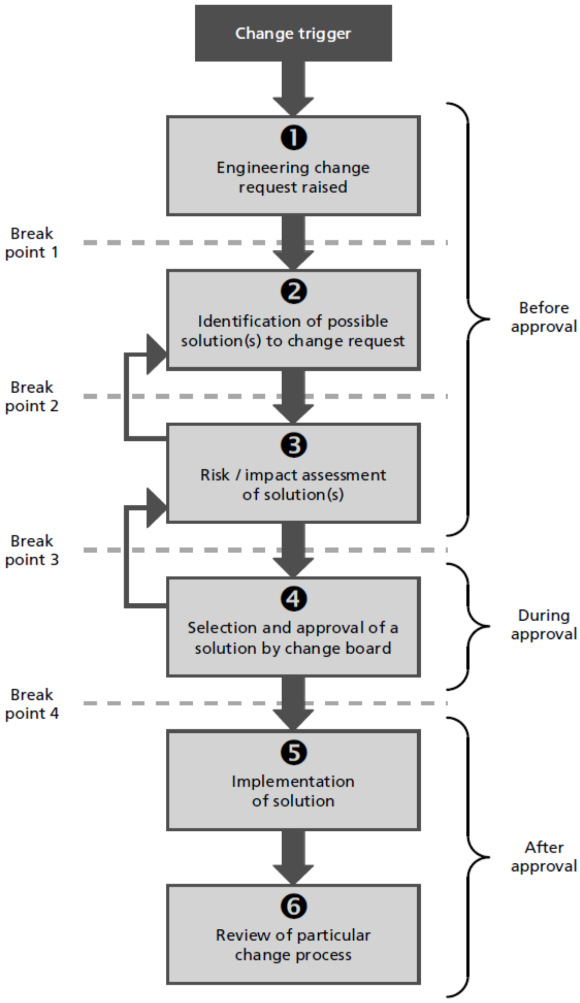


Figure 2-4 The engineering change process pattern (Eckert et al, 2005, p.272)

Before the product enters the manufacturing phase, not only the product data but also the production process and resource data are also required, which involves the corresponding disciplines/departments, e.g. the process planner and tooling designer cooperate together with the product designer to ensure that manufacturability and downstream works are executable. This brings the challenge of how to accelerate the work process in multi-department collaboration.

The traditional hierarchical organizations and sequential development method face problems in rapid changing and higher competitive markets (Sorli and Stokic, 2009, p.12; Fleischer and Liker, 1997, p.9). Poor communication among departments and consideration of downstream work, e.g. manufacturability issues, brings about unnecessary reworks and results in long lead time and high development cost.

To improve the situation mentioned above, the concept Concurrent Engineering was introduced and has been widely adopted in new product development since the 1980s.

2.2.2 Concurrent Engineering (CE)

Concurrent Engineering is not a new concept for the manufacturing industry. There are plenty of application cases and research papers, although literature review shows that interest in this topic has decreased over the last decade (Addo-Tenkorang, 2011). A widely accepted definition of CE is given by Pennell and Winner (1989):

"Concurrent Engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including, manufacturing and support. This approach is intended to cause the developers from the very outset to consider all elements of the product life cycle, from conception to disposal, including cost, schedule, quality and user requirements."

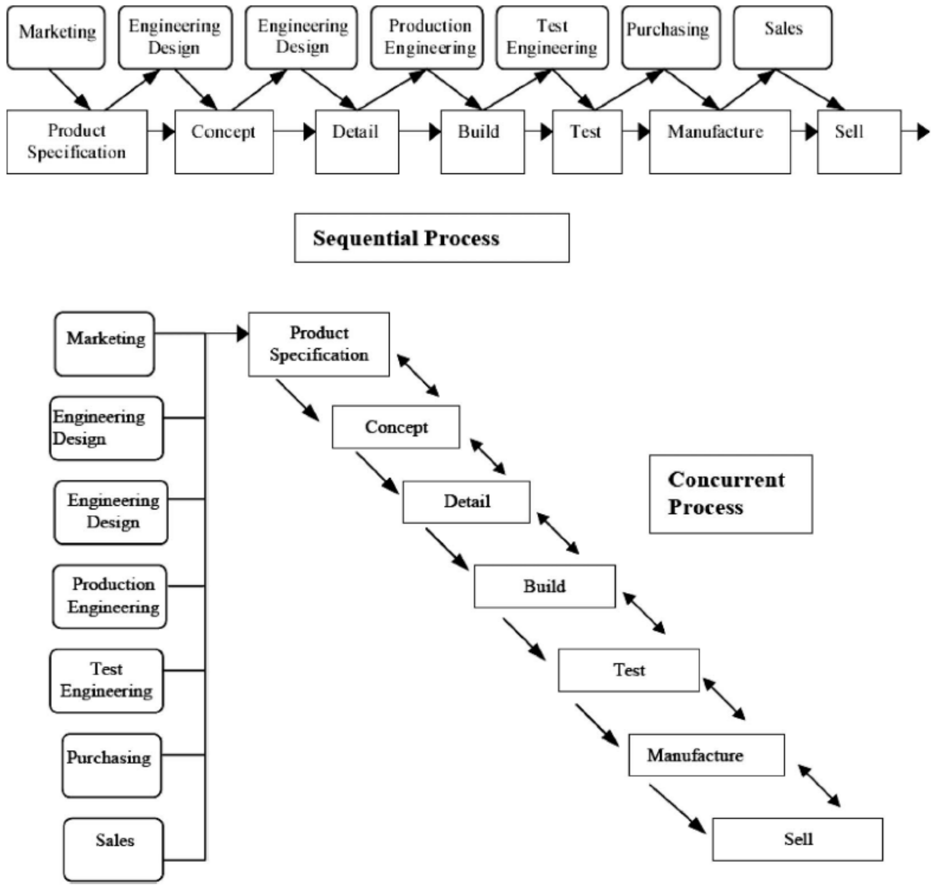


Figure 2-5 The sequential (traditional) and concurrent (simultaneous) product development process (Pullan et al., 2010)

By applying the CE method, a manufacturing company is promised to benefit from a reduction in product lead time to market, higher product quality and less cost (Fleischer, and Liker, 1997; Ranky, 1994, p.22). To gain the reward, applying CE in enterprise means broad and deep changes. The conventional sequential work process has to be changed to parallel activities in order to shorten the development cycle, connect disciplines or functional departments to reconstruct into multi-disciplinary teams to enhance communication. Meanwhile, a corresponding supporting environment is set up to facilitate information exchanges in collaboration (Pullan, et al., 2010).

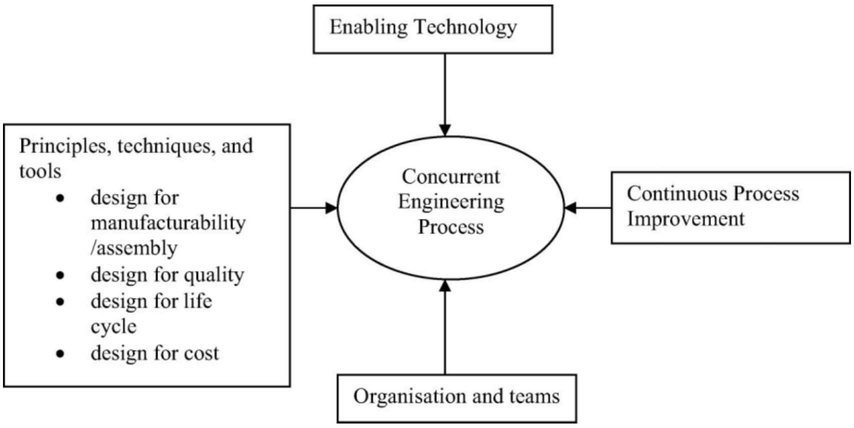


Figure 2-6 A framework of Concurrent Engineering (Pullen et al., 2011)

Regarding the last element, computer aided engineering tools e.g. CAD (Computer Aided Design)/CAM (Computer Aided Manufacturing) could facilitate 3D model building, analysis, sharing and manufacturing process simulation to address DFX (Design For manufacturability, cost, quality, et al.), integrated with other tools such as QFD (Quality Function Deployment), FEMA (Failure Mode and Effect Analysis) to robust product design and efficient production (Ranky, 1994, Chapter 3).

2.2.3 Development of CE - the Collaborative Engineering

Around the 1990s, alongside the process of globalisation and spreading of industry, more and more products were developed by the joint effort of companies and teams geographically distributed (Mills, 1998, p.3). The growing complexity of cross organisation cooperation and development of information technology fostered the concept of Virtual Enterprise (VE) and Collaborative Engineering (Mills, 1998, p.20; Figay and Ghodous, 2008).

In the white paper (2004) of MESA (Manufacturing Enterprise Solutions Association), Collaborative Manufacturing is defined as:

> *A strategy by which all appropriate individuals and organizations– both internal and external to the legal enterprise – work together. The objectives of such a strategy are to streamline end-to-end business and supply chain processes and provide a more comprehensive and accurate information base from which to make decisions.*

Compared to Concurrent Engineering that stresses a cross-discipline team approach and parallel workflow, Collaborative Engineering focuses more on creating an effective environment to enhance peer-to-peer communication and interoperability, especially for distributed product development and manufacturing (Mills, 1998, Chapter 1).

Other works (McClellan, 2002; Li and Qiu 2006; Willaert et al., 1998) also indicate that collaborative manufacturing is more suitable to provide a wider scenario to better facilitate joint-work and decision-making issues in large scale product development and distributed manufacturing with suppliers, although the core philosophy foundation is still the Concurrent/Simultaneous Engineering.

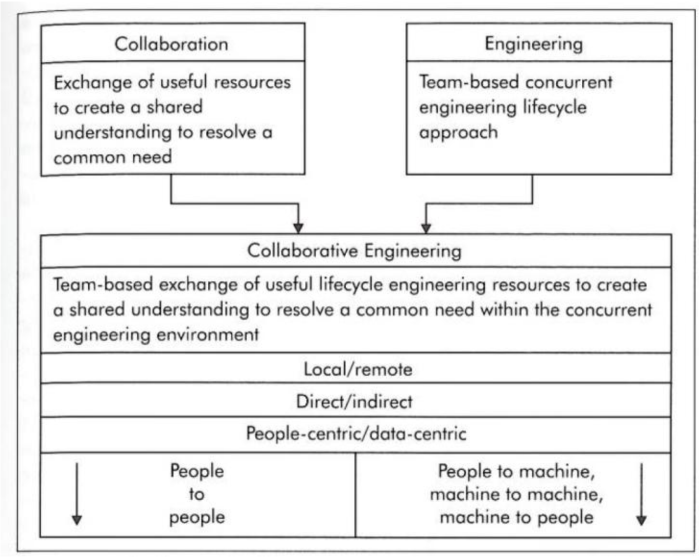


Figure 2-7 The fusion of collaboration and engineering (Mills,1998, p.7)

Mills (1998, p310) states that the fundamental elements of collaborative infrastructure are:

- *Hardware;*
- *Software;*
- *Network;*
- *Infrastructure training; and*
- *Support and administration*

Enabling collaborative participants to exchange information freely is the basis of successful communication, which could be seen as an interactive cognitive process between information sender and receiver (Eckert et al. 2005, p.237).

Sorli and Stokic (2009) define the Collaboration pattern as comprising three aspects: *Temporal, Spatial and Rules*. The Temporal pattern could be *synchronous, asynchronous and multi-synchronous*. Shen et al. (2013) point out that the synchronous and asynchronous are two primary modes.

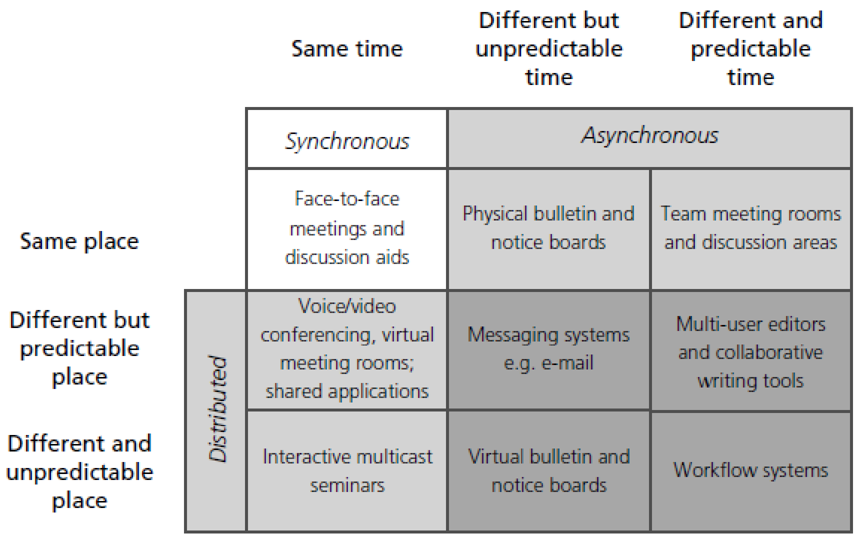


Figure 2-8 Communication in computer supported cooperative work (Eckert et al., 2005, p.255)

Eckert et al. (2005, p.243) also present the interaction scenarios of communication in PD, as depicted in Figure 2.9. The joint design normally refers to people working co-locally and with face-to-face communication. However, the increasing trend of remote design and remote communication tools make dispersed joint-design activity possible (p.242).

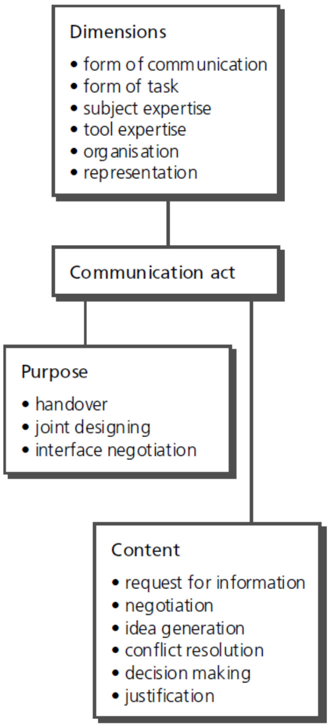


Figure 2-9 Communication pattern in PD (Eckert et al., 2005, p.243)

Willaert et al.(1998) point out that to achieve collaboration when entering into large scale and complex product development, an integrated supportive environment for all team members which links different platforms e.g. CAD/CAPP (Computer Aided Process Planning)/PLM (Product Lifecycle Management)/MES (Manufacturing Execution System) is necessary. The downstream activities such as manufacturing and cost estimation need to be seamlessly integrated into CE-based collaboration. The work process and data flow control also need to be fully designed to improve joint-design and cooperation, which is crucial for its successful implementation.

2.3 Aircraft Assembly Line and CE

Aircraft is a typical large scale complex product, and the principle of Concurrent Engineering (CE) has been applied in this industry for decades. Early reports indicated that Boeing has benefitted from 30% cost reduction by applying CE (Pennell and Winner, 1989). Later data shows that the aerospace industry reaps on average 40% product development cycle-time reduction and other benefits (Pullan et al, 2010).

A case study describes the CE measures Boeing took in the B777 project, such as cross-functional team working and 3D models of product data to achieve project success (Swink et al., 1996). In another research report, by Jørgensen (2006), the development phases of B777 are studied. The author argues that the project followed a waterfall life cycle rather than the iterative process. The influence of the digital design method on accelerating project progress is also confirmed. However, in a report from NASA, the development process taking the concurrent engineering way rather than the traditional method, benefits from well refined program stages and new technology such as 3D pre-assembly which could promote the achievement of reduced lead time and reworks (Spitz et al., 2001, p.3-11).

In a civil aircraft design book (Jenkinson et al, 1999, P27), a small paragraph is used to explain the role of CAD and CE in aircraft design. A whole chapter (Chapter 5) of Fan's work (2001) discussed the application of CE in aircraft manufacturing, especially IPT (Integrated Product Team) and involvement of computer aid tools in the case of how the Boeing company implemented CE in the B777 project. Rupp (2004) introduced the experience of and a lesson learned from deploying the collaborative tool in the MTU aero engine, and suggests that the communication tool (WEBex) needs to integrated with PDM for better communication. The users' training and acceptance are also very important for successful implementation.

In the case of Airbus, PDM (Product Data Management) and CAD support the use of DMU (Digital Mock-Up) which plays the key role in CE deployment (Pardessus, 2004), and in a further development, the CE upgraded to collaborative engineering and DMU evolved to iDMU (industrial DMU).

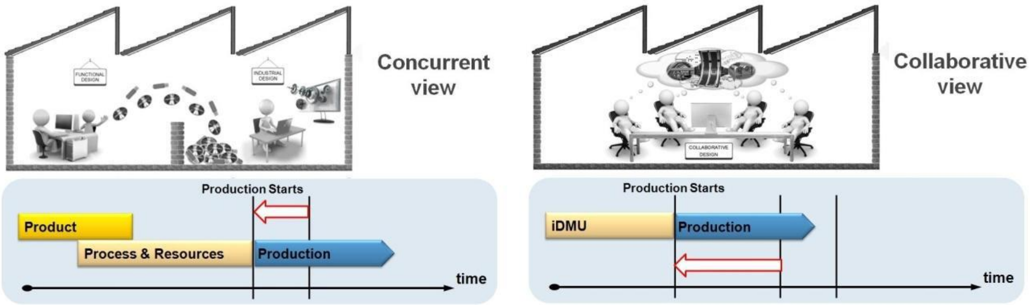


Figure 2-10 The different view of Concurrent Engineering and Collaborative Engineering in Airbus (Mas et al, 2013)

In a report concerning the global efforts of B787, Kotha and Srikanth (2013) reported the problem of co-location in this project. They find that Boeing faced integration challenges relating to:

(1) design integration;

(2) production integration; and

(3) supply chain integration.

Production Integration Centre (PIC) were deployed to reinforce the integration of global product development systems, especially by providing strong expert support and remote communication between Boeing and suppliers. Finally, this centre served *as the mission control for the 787's global supply chain.*

The paper of Shehab et al.(2013), shows the efforts of Airbus to try to develop effective data sharing access ICT (Information and Communication Technology) between Tier-1 suppliers and OEM (Original Equipment Manufacturers by using particular commercial software.

As pointed out by Munk, C. (2009), "Aircraft manufacturing and assembly", in: Springer *Handbook of Automation*, Springer Berlin Heidelberg, pp. 893-910.diverse technologies are employed in aircraft manufacturing, especially computer controlled machines. Although the automated assembly line has greatly improved the productivity of modern aircraft, systemic and development work is still needed. Various tailored and dedicated NC machines are used in civil aircraft fabrication and assembly. Automatic assembly lines that normally combine traditional tooling (fixture), numerical controlled machines or robots, auto-positioning and inspection equipment have become a trend for aircraft builders in order to realise higher quality products in a more efficient way than manual operation.

In the report from NASA (Spitz et al, 2001), the estimated expenditure on designing tooling, facilities and industrial equipment takes 1/5 of the total cost in the design cycle phase for a new civil aircraft model (Table 3.1). The time of developing tooling, facilities and industrial equipment is estimated at 42 months for an 8 year-long airframe development model of the 1990s (Figure 2-11 State-of-the-Art Airframe Development).

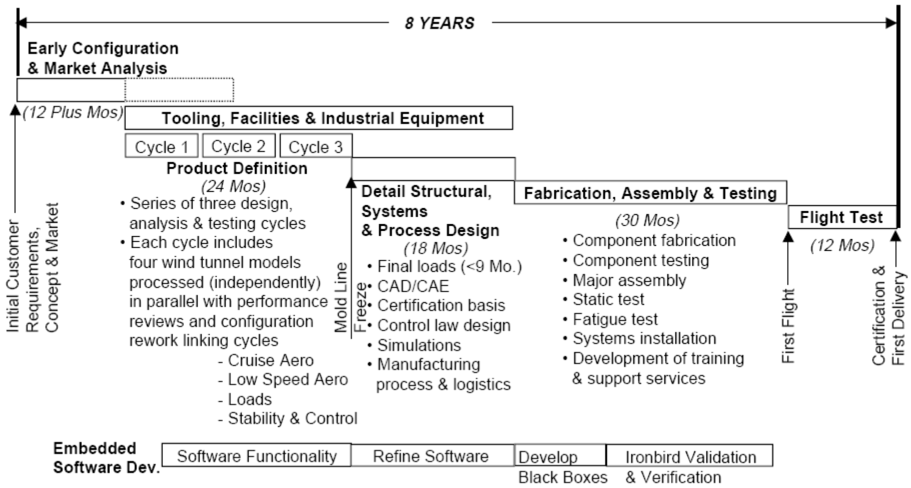


Figure 2-11 State-of-the-Art Airframe Development Cycle (Spitz et al., 2011)

In this report, four major target areas of cycle time reduction are identified over the next several years. These are:

- *Reducing engineering man-hours;*
- *Reducing tooling hours;*
- *Reducing test activity; and*
- *Implementing process and information technologies.*

To realise the goal of shortening lead time and applying information technologies in tooling/production line development, the context and content must be fully studied. In the book: *CAD Method for Industrial Assembly: Concurrent Design of Products, Equipment, and Control Systems* (Delchambre, 1996), the issue of integrating CAD with CE to accelerate the assembly line development process is addressed, and the research process guides this research (pp.5-7):

- Define the user's needs
- Analyse the user's requirements and propose a solution
- User evaluates the demonstration and gives feedback
- Find reference about assembly line design process & content

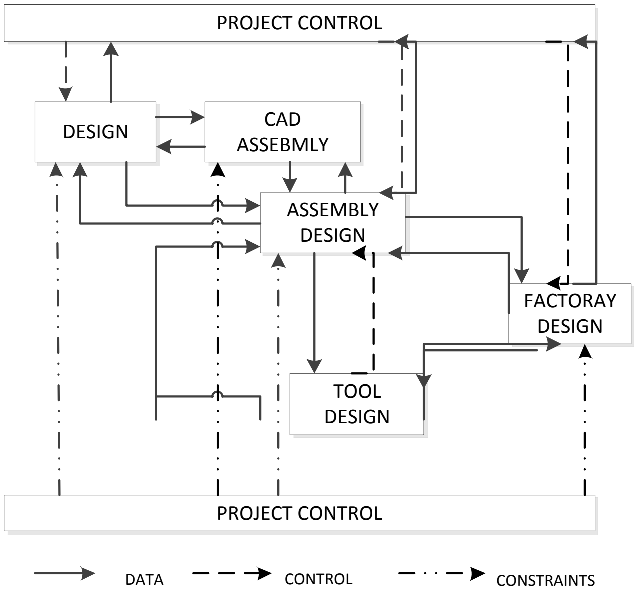


Figure 2-12 The CAD and AL design(Reproduced from Delchambre, 1996, p.240)

Assembly in large scale product needs to deal with *logical, logistical, financial, and operational issues of making products from parts* (*Delchambre, 1996,* p.237). For assembly planners, their work process can be divided into three steps (p110):

1. *Assembly modelling*
2. *Generation of actions and constraints;*
3. *Creation of assembly plans.*

In a later work on AL, the elements of concurrent design of AL are showed as Figure 2-13 Concurrent *design of an AL (Rekiek and* Delchambre, 2006, p.5)

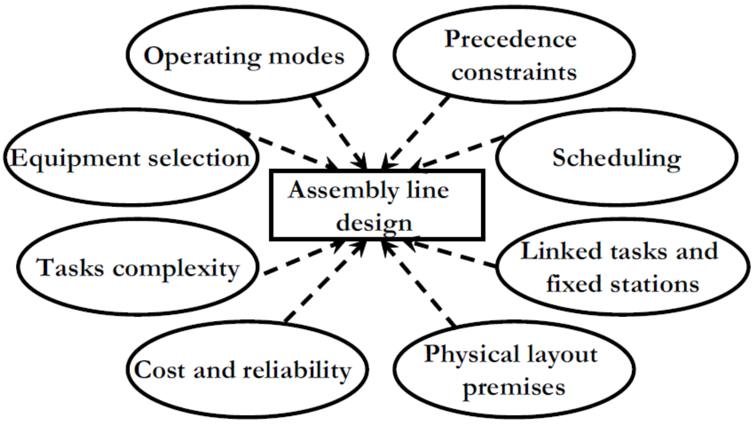


Figure 2-13 Concurrent design of an AL (Rekiek and Delchambre, 2006, p.5)

The technology of CAD enables AL designers to perform simultaneously with product designers, reduce development time and improve reaction. By simulating the complicated AL operation with 3D models, multi-discipline works are conjoined together and verified (*Delchambre, 1996,* Chapter 10). In Fan's book (2001), a detailed CE approach and digital tools of design and building tooling for aircraft manufacturing are studied. The practice of implementing CE in Boeing and the importance of integrating a data platform like PDM is demonstrated.

Tooling or large fixture for supporting the airframe is one of the main elements in the aircraft assembly line. The design process and information flow between upstream (aircraft designer) and downstream (tooling designer) is analysed by Li, et al. (2008), and the approach to build the relationship between aircraft product and tooling on PDM platform in collaborative tooling design is proposed.

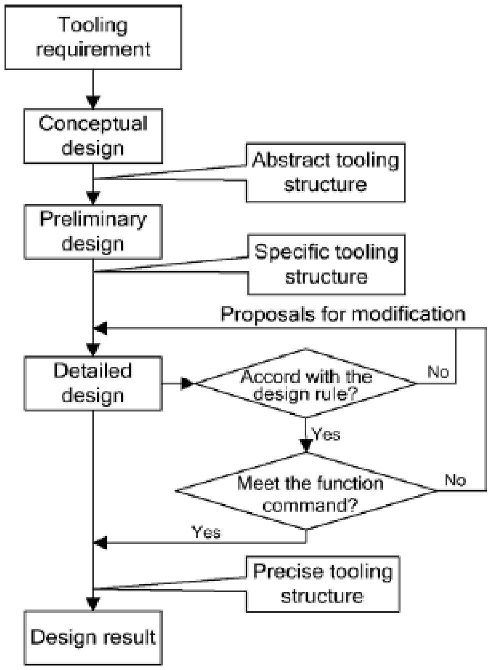


Figure 2-14 A closed loop aircraft tooling design process (Li, et al., 2008)

Rekiek and Delchambre (2006) introduce (Chapter10) the concurrent assembly design process. The repeated loops of preparation, optimisation and mapping are demonstrated, in which a common data base is required for multi-disciplined team members' joint design.

Mas et al. (2008) tried to use Knowledge Based System (KBS) in concurrent design method in the conceptual design phase of aero-structure assembly, by introducing a process oriented conceptual design process for AL. The assembly design model decomposition of the activity and its associated knowledge units: product, process, and resource, are mapped in IDEF0 and CATIA scenarios. However, the wider collaborative relationship between final user and supplier in the real world is not discussed.

2.4 The supporting systems for CE: CAD/PDM/PLM/ICT

In the report of Willaert, et al. (1998), the information infrastructure of CE is divided into three subjects:

- *Collocation tools;*
- *Coordination tools;*

- *Information access and corporate memory.*

The purpose of collocation tools is mainly to increase communication amongst team members, and the coordination tool is designed to improve the information management, e.g. configuration control, document releasing and tracking. The information access and corporation memory enable participants, whether individual team members or departments, to access the right data they need and record decision making in the design process.

The data management and exchange between members are regarded as the core function of the supporting environment for concurrent/collaborative engineering (Mills, 1998; Rouibah, 2003). Before going through the work platforms, the definition data, information and knowledge need to be reviewed, as shown in Table 2.1.

Table 2-1 The variants of content in for communication (reproduced from Mills, 1998, p.45)

Content name	***Content Description***	***Level of I/O***
Data	*Raw-numbers, symbols, text*	*Information exchange*
Information	*Meaningful data- Involves units of measure*	*Information exchange, communication*
Knowledge	*Deterministic process based on 'memory'*	*Communication, collaboration*
Understanding	*Probabilistic, interpolative process based on 'learning'*	*Collaboration*

Wisdom	*Extrapolative process-Addresses effects in the future*	*Collaboration*

The document is defined as the container of information with various formats such as digital or hard copy of picture and file on a certain medium, in the standard of ANSI/EIA 649(ANSI/EIA, 2001).

Willaertet al. (1998) also implies that data management is the more crucial issue for distributed teams. The lack of information technology support and process improvement may lead to unsuccessful CE implementing.

Shen et al. (2001) report the use of agent technology and application in concurrent engineering in their work. They also point out that competent tools like CAD, database and coordinated environment are the foundations of efficient distributed design. Due to the increasing product and collaboration complexity they also suggest in their work that the next-generation of concurrent design and manufacturing system should be/with (p.24):

- *Time-oriented*
- *Enterprise Integration and cooperation*
- *Heterogeneous environment*
- *Interoperability*
- *Distributed Concurrent Engineering Issue*
- *Agility*
- *Scalability*
- *Fault tolerance*

Sorli and Stokic (2009, P.161) indicate the specific requirement of ICT for collaborative product/process design, compared to the summaries of Shen et al. (2008) (see Section 2.2.3), where Sorli and Stokic place more stress on dynamic change management ability.

Jianyu et al. (2012) propose a web-based PDM System for the Collaborative Design, which consists of four layers: data storage layer, system services, business layer, and user interface.

Pullan et al. (2010) reviewed related research works on manufacturing technology and mapped out the relationship of different technology and concepts. They also suggest an object-oriented manufacturing process information model.

Mills (1998, pp.109-116) indicates that the Product Data Management (PDM) is a critical tool in product development, and specifies that the main functions of PDM should include management of the product data, configuration, EC process and the ability to be integrated with other system such as MRP/ERP.

The specific benefits of adopting PDM include: reduced time on storing, transiting, and searching time, as well as the structured format improving the use and security. Workflow management is also available based on the data management function. Therefore, PDM could be the core component of a Product Lifecycle Management (PLM) system (Stark, 2011, Chapter 10). PLM uses a holistic approach to management product and the relationship and involved activities and elements of PLM are illustrated below. The benefit of implementing PLM for enterprise is suggested to be an increase in product revenues of 30% and a decrease in product maintenance costs of 50%. PLM constitutes several functional modules of PLM, e.g. Computer Aided Design (CAD), Product Data Management (PDM), Computer Aided Process Planning (CAPP), Component and Supplier Management (CSM), Computer Integrated Manufacturing (CIM), and so on. Stark stresses that PLM includes product, people, application and process, where no element shall be an isolated island. In the MESA white paper (2004), the workflow from planning to execution on various platforms (CAD/ERP/CAPP et al.) in collaborative manufacturing is illustrated.

Chen and Hsiao (1997) proposed a collaborative team data management framework which allows development members to work concurrently in a team with the ability to:

(1) model and manage a project for product and process development,

(2) model a product structure that is related to a defined project, and

(3) manage and share product and process information through the entire product and process development cycle.

The globalisation of supply chain brings the issue of interoperability caused by a distributed, heterogeneous collaborative environment. OEM and suppliers may use different CAx/PDM software, and data exchange and workflow management become critical issues for establishing a collaborative environment.

Li and Qiu (2006) categorise the collaboration into three types: *visualisation-based collaboration, co-design collaboration and CE-based collaboration*. Implementing a co-design method needs real-time communication/data exchanging tools to support it. The character of the latter is an integration of cross discipline and distributed development process.

Rachuri et al. (2008) summarise standards of product information sharing in PLM.STEP standard for product modelling and exchanging, XML-based protocols for information exchanging like STEPml and PLM XML, and product visualization standards such as X3D, JT, and OpenML are introduced.

Yang et al. (2008) proposed the STEP and XML based open PDM system to realise data exchange across different commercial PDM software.

Gunpinar and Han (2008) indicate that there are two ways for product information exchange between PDM systems: direct translation and via standard format as a vehicle. The OMG PLM system is introduced using STEP and XML based data format for exchanging product information.

The emerging web-based technology propelling collaborative product development has attracted research interest in recent years, as summarised in the report of Smparounis et al. (2009).The work platforms are suggested as constituting:

1. A Web-based Collaboration platform

2. A Collaborative CAD module
3. A Virtual Reality module(s)
4. A Decision Support module

Kovács(1999) and McClatchey et al. (1998) argue that the ability of PDM and WFM systems to handle dynamic change still needs to be improved.

In their study Qiu and Wong (2007) realised the dynamic workflow management in a PDM system, demonstrating the changing of workflow instance from template in implementation. They also argue that the data integrity and workflow traceability are necessary for averting errors.

Data version management is important in daily updating the PD progress. The instance of CRISTAL (Cooperating Repositories and an Information System for Tracking Assembly Lifecycles) system and the data version management in dynamic workflow in distributed PDM systems is introduced by McClatchey et al. (1997).

In the research paper of Ming et al. (2008), an example was given to demonstrate that the detailed work flow and supporting system in collaborative manufacturing in PLM components are mainly CAD/CAPP/CAM.

The process of transforming EBOM (Engineering Bill of Material) to MBOM (Manufacturing Bill of Material) from PDM to ERP is discussed in the work of Lee et al. (2011), and the role of MRP (Manufacturing Resource Planning) in this process is introduced in the paper by Huet et al. (2009). Another scenario named *smart factory* for aircraft manufacturing industry aiming to enhance the Triple P (*productivity, price-recovery and performance*) is proposed in the work of Rashid et al. (2012).

The work of Chryssolouris et al. (2009) provides an overall description of the perspectives of both digital manufacturing and industry practice. The author emphasises that although current information platforms can support digital and distributed manufacturing, data and knowledge management should be of more serious concern for better implementation in the future. Although there are plenty of commercial solutions available on the market, Watts (2005) argues that current work platforms like PLM/ERP still do not provide efficient communication support for users in PD.

To successfully implement PLM in practice is a challenge. Stark (2011) stresses the importance of system integration. The case study conducted by Merminod and Blanco (2008) shows the problems relating to data transferring, workflow and so on, which are encountered in the application of PLM in enterprises. If the new work platform could not adapt work conventions formed in pre-PLM environment, the effect will be undermined and people may try to find off-platform methods to speed up their activities.

The review report of Dekkers et al. (2013) is useful to understand the relevant research works and practice of the past 20 years. As they assert, the theory and tools for concurrent/collaborative engineering still need to be further developed, whilst PLM should pay more attention to both work flow and data management.

2.5 Work Process & Information flow modelling

Not only aircraft but also the assembly line are complex products and need enormous joint effort to develop. The design process management is crucial to achieving goals such as DFX, time, cost and so on.

Data, process and functional modelling are methods and tool sets for CE (Ranky, 1994, p.70). In the paper of Shen et al. (2008), the importance of interoperability for designers from diverse disciplines is emphasised and collaborative design process modelling is promised as a proper tool.

Vajna (2005) discusses workflow modelling in the design process and suggests a definition of key terms as follows:

A process *is a meaningful set of activities or sub-processes to solve a class of possible tasks. The combination of activities and/or sub-processes is always flexible and can be adapted dynamically to a specific task.*

A workflow *is a dedicated, rigid sequence of working steps, process elements or sub-processes, e.g. a release workflow, which is not changed.*

The workflow could be regarded as a set of tasks in a certain order, which could be executed by corresponding entities (people, machine, organisation) with given resources and procedure (Stark, 2011, p.212; Georgakopoulos et al., 1995).

Collaborative product development is a highly interactive process of multiple participants, where the job design needs to be defined (Fleischer and Liker, 1997, p.40). Three task interdependence types are defined as: *pooled, sequential and reciprocal*. Kolfschoten (2007) suggests that the two critical challenges needing to be addressed are:

1. Process definition

2. Support participants' collaboration.

In the case study of adopting CE in cross-company collaborative PD, Rouibah (2003) finds that to decompose and express the work process at a proper detail level is difficult. He also finds that engineers regard the design process as more parameter related work rather than document or process based.

The work process in concurrent or collaborative product development is also a part of business processes. Georgakopoulos et al. (1995) propose process modelling and reengineering as the approach to improve workflow management. They also suggest three process modelling approaches as:

- *Communication-based methodologies*
- *Activity-based methodologies*
- *Object-oriented methodologies*

The classic tools of business re-engineering such as CIMpgr, DFD and IDEF0 is introduced by Ranky (1994) to analyse work and data flow by diagram. In the report by Mayer et al. (1995): *Information integration for concurrent engineering (IICE) compendium of methods report*, the development of an IDEF modelling tool family for supporting CE is summarised. Prasad et al. (1998) advocate the concurrent work flow management and regard the Flow Chart as a useful tool of work process description and improvement.

O'Donovan, et al. (2005, p.67) point out that building a design process model could help to increase design efficiency by capturing the information inputs and outputs among design individuals. Workflow modelling is not only a descriptive tool but could also assist analysis of and improvement to the workflow performance (Prasad et al., 1998; Aguilar-Savén, 2004). Changing sequential work flow to parallel style through modelling of work/information flow is an important job for deploying CE. The work process of such includes the following elements (Fleischer and Liker, 1997, p.28):

- *Activities*
- *Flow of information and objects between activities*
- *The order and timing of activities*
- *Control mechanism*

The four approaches to work flow modelling needing to be discussed are:

- *Descriptive*
- *Schedule-focused*
- *Flowchart*
- *Phases and gates*

Aguilar-Savén (2004) reviewed some tools for business process modelling, including Flow chart, Data Flow Diagram, Role Activity Diagrams—RAD and Role Interactivity Diagrams (RID), Gantt chart, IDEF, Coloured Petri-net(CPN), et al. He also suggests that the Flow Chart tool is flexible and easy to use.

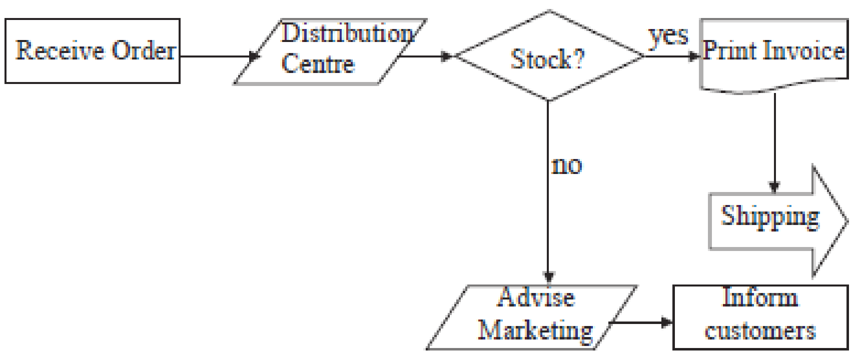


Figure 2-15 An example of flow chart (Aguilar-Savén, 2004)

2.6 Summary of Literature Review

2.6.1 Main findings

Concurrent Engineering is a beneficial tool for accelerating product development, and the further development of it for distributing product development is Collaborative Engineering. Both approaches need strong computer-aided/information tools to realise data management, information exchanging and remote work flow management and so on, which provide a crucial foundation for cooperation efficiency and interoperability.

2.6.2 Research gaps

In depth research on implementing concurrent/collaborative engineering in aircraft assembly line is still in low number.

The detailed study of data flow and workflow in complex product development is crucial for enterprises implementing concurrent engineering. However, from the review of available work, this topic still lacks appropriate attention (Georgakopoulos et al., 1995; Prasad et al., 1998, Qiu and Wong, 2006; Vila et al., 2007).

2.6.3 Limitation of this Literature Review

Mainly due to time limitation, this literature review only studied the main aspects of CE and its development as well as with the supporting tools. The application of CE in aircraft assembly line development is short of relevant materials. Further study regarding iterative design loop, constraints, coordinating and decision making mechanism in the CE would be beneficial in future research.

3 Methodology

3.1 Baseline of research method

The main purpose of this research project is to find and assess the application of concurrent engineering in AL projects in SAMC, and to identify opportunities for improvement. To build the research approach, a number of works are used as main references. The most important is Fleischer and Liker (1997), in which the complete roadmap and examples for CE implementation are provided. Other works used to build the research include: Delchambre (1996), Forsberg and Johansson (2008), Rouibah (2003), Savant and Al-Ashaab (2009). The research roadmap is shown below:

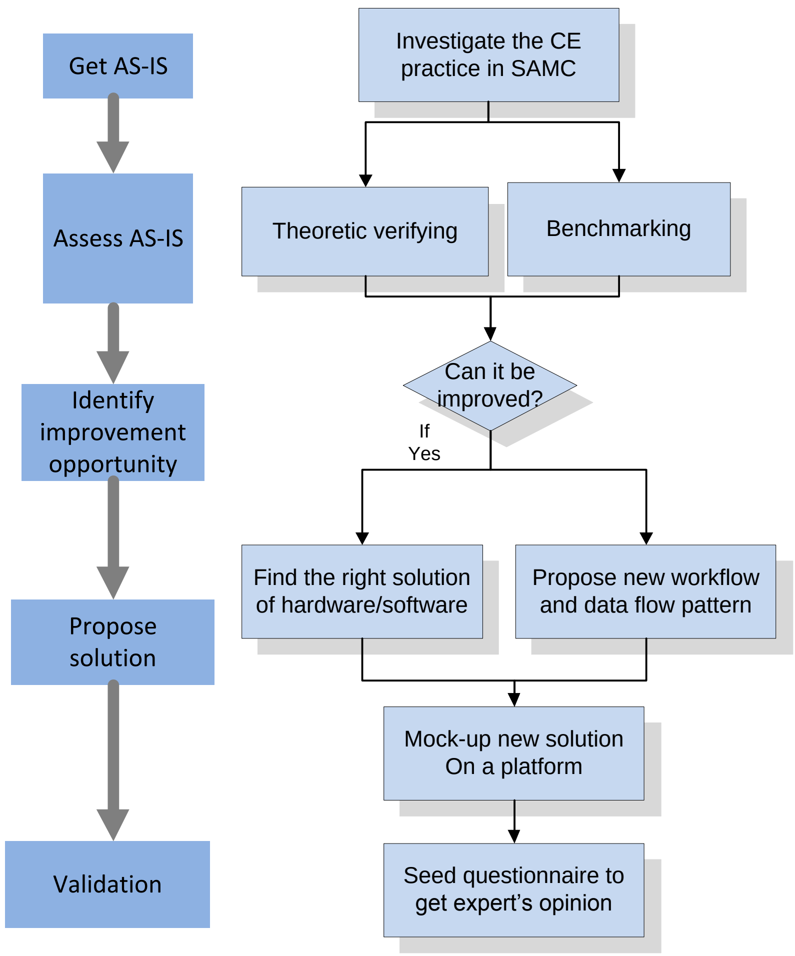


Figure 3-1 The research path

3.2 Data collection and assessment method

To improve the CE practice in assembly line design, the first step is to understand the current practice. The data collection contains three aspects:

- People and Organisation, e.g. disciplines and team structure;
- Technologies, e.g. design and communication tools
- Work processes and coordinating mechanism, e.g. how is the design loop executed? Which kind of data constitutes the input and output for a member in the design loop?

The data collection was carried out in four ways:

1. Summarising the work experience of the author in AL projects to obtain empirical data;
2. Investigation with obtainable documents and data of AL projects;
3. Interview with people who are working on AL projects;
4. Semi-structured questionnaire for particular questions as necessary.

The summary of work experience and direct investigation was documented in the AS-IS report. To avoid the effects of personal bias and limitation of work experience, informal interview and formal questionnaire were used as supplement. Interviewees mainly consisted of AL project participants including project managers and engineers from SAMC or suppliers. The questionnaire questions were designed to elicit key information and the results were signed off by all interviewees. Due to the geographic distance of SAMC from Cranfield University, remote communication including E-mail, telephone and video conference were employed in the data collection process.

For the evaluation of obtained data, the elements of AS-IS were compared with the theories in Chapter 2, and then, published practices were used to identify the weakness and improvement opportunity as suggested by Fleischer and Liker (1997, p.243). The researcher needs to measure performance, process and structure before benchmarking with others to reach consolidated conclusion.

The work process element requires more work. As Fleischer and Liker (1997, p.248) suggest, work process evaluation was done in four steps:

1. *Map As-Is Process*
2. *Document Formal Process*
3. *Match As-Is to Formal*
4. *Map Strengths and Weaknesses*

In this research, the workflow was mapped by Flow Chart tools, as referred to in Section 2.6. Finally, the result was compared with criteria and industry benchmarks, to find the advantages and drawbacks of the current situation.

3.3 Solution Design and Mock-up

In the second stage, the improvement opportunities were identified based on the evaluation in the last stage.

To address the weakness in CE supporting environment, research reports reviewed in Chapter 2 were referred to and benchmarks such as Boeing and Airbus were compared. Potential solutions must be able to improve the CE practice whilst complying with the SAMC infrastructure and the work convention. Finally, the proposed solution would be mocked-up using mainstream commercial software to test the applicability. Due to the issues of confidentiality and resource limitation, the mock-up could not use the AL project data from SAMC but a similar and simplified testing data were constructed on the platform.

3.4 Validation

After the proposed work process and data flow model had been mocked up, the result with the core findings of AS-IS were documented as a questionnaire and sent to people from SAMC and suppliers working in the AL project. As shown in Fleischer and Liker (1997, p.283) and Kolfschoten (2007, Appendix F), the feedback were analysed to indicate to what extent the proposed solution could satisfy users' expectations.

3.5 Summary of Methodology

The research methodology of this project followed the case study approach as shown in Section 3.1, which was designed to meet the research objectives within the available resources.

The main limitations concern three aspects:

- The confidential issue made the data collection difficult and some evidences were impossible to show in public.
- The geographical distance made the investigation and communication difficult between the researcher and the research object.
- Due to the time and tool limitation, the proposed solution could not be directly verified by deploying it in the AL project to obtain complete and real operating experience and users' feedback.

4 Data collection

4.1 Objectives and approach

4.1.1 Main objectives of data collection

To design and build an aircraft assembly line requires many years of work. To map out the entire work content and activities would be an enormous task and not realistic within the time constraint of this research. Hence, the scope was to capture the AS-IS work process and context in a specific phase of the aircraft assembly line development in SAMC.

The first step was to investigate the context of CE is about factors that affect the joint-design of the customer (SAMC) and its suppliers in assembly line developing. This consisted of four aspects (Fleischer and Liker, 1997. Chapter 2):

1. *People*
2. *Organization*
3. *Technology*
4. *Strategy*

The environment outside the AL project was less important, so not included in the research scope (Fleischer and Liker, 1997, p.33).

A key part of this research was to streamline the information transfer in AL design. The entangled relationships of numerous departments and roles need a holistic picture to help understanding and optimisation. Hence the work process was given more attention and the author mapped out the current workflow using the flow chart tool. However, the high level view did not convey the detail practice at the lower level, so the overall workflow was broken down to help discussion.

After data collection, the author assessed the AS-IS to analyse the benefits and drawbacks. This followed the process suggested by Fleischer and Liker (1997, p.248):

1. *Map As-Is Process*

2. *Document Formal Process*
3. *Match As-Is to Formal*
4. *Map Strengths and Weaknesses*

Similar to the IDP (Integrated Product Development) of Texas Instruments (Fleischer and Liker, 1997, Chapter 3), SAMC adopted a structured assembly line development process with some slight differences. The first stage consisted of collecting design concepts from bidders and finalising the final contractor. Then the preliminary design would start. The remaining development cycle was marked by three main milestones, which were: PDR (Preliminary Design Review), CDR (Critical Design Review) and FDR (Final Design Review). To speed up the delivery, prototyping and testing were included in the detailed design phase and manufacturing work would start after CDR, in parallel with the final design.

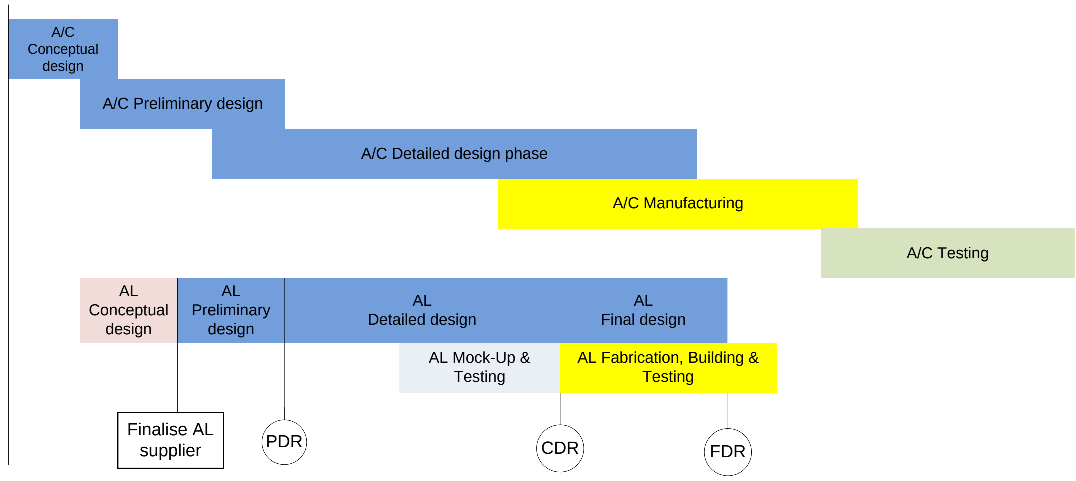


Figure 4-1 The Development Process of C919 Aircraft (A/C) and Assembly Line (AL)

One difference from other developed patterns was that in the SAMC assembly line projects, the Detail Design phase was separated into two parts by the CDR milestone, and the last phase was called the Final Design Phase where a major fabrication job would be launched. At the CDR milestone (Fleischer and Liker, 1997, Chapter 3), the maturity of AL designs would be carefully checked, at which critical product characters must be satisfied. Only when engineering was judged ready to support AL fabrication, then the relevant manufacturing work would start, subject to any final modifications and elaborating works.

This thesis mainly focused on the phase between PDR and CDR, namely the Detail Design phase. While the primary assembly plan, assembly line layout, tooling list, equipment specifications and other elements had been chosen and approved in the previous phase, the design team would still need to work on continuously modifying, enriching and elaborating the AL design while the A/C design progresses. A number of prototype testing tasks would also be planned in the project schedule for the suppliers.

4.2 AS-IS Situation

In this section, the author describes findings from the investigation as in Section 4.1. As the CE context helps to understand the work process, it will be discussed first in this chapter.

4.2.1 The SAMC and Supplier Context - people and organization

Despite the wide range of SAMC people engaged in the collaborative work with the supplier in the Detail Design phase, the majority of the design activities were undertaken by several core disciplines drawn from a smaller number of departments, whose people comprised the cross-function design team. A senior engineer was assigned as the team leader and was responsible for achieving the key technical goals, but not responsible for the daily running of the team. The daily work was coordinated by a more junior project engineer (see Fleischer and Liker, 1997, Chapter 3). The functional departments not only provided members to the team but also required to provide the necessary expertise. Liaison people from other supporting departments such as cost and procurement were also included in the team, to enable team members to find specialist help quickly. As a result the SAMC AL team had the typical matrix structure as categorised by Fleischer and Liker (1997).

Table 4-1 The main internal staff involved in AL design

No.	Role	Responsibility in Assembly Line development
1	Senior Engineer	Charge for key technical issues
2	Project manager of assembly line(AL)	Define the project scope/scheduling/check work progress
3	Assembly engineer	1.Co-design assembly plan/resource plan with supplier 2.Assess the solution of supplier 3.Manufacturablity Assessment and feed back
4	Tooling designer	Assessment Tooling design of supplier
5	Equipment engineer	Check equipment specification
6	Quality engineer	QFD(Quality Function Deployment)
7	Facility and resource planning engineer	Assembly line operation simulation/ resource preparation
9	Other supporting department: Cost/Production/Procurement, et al.	Calculate/estimate cost, lead time of AL et al.

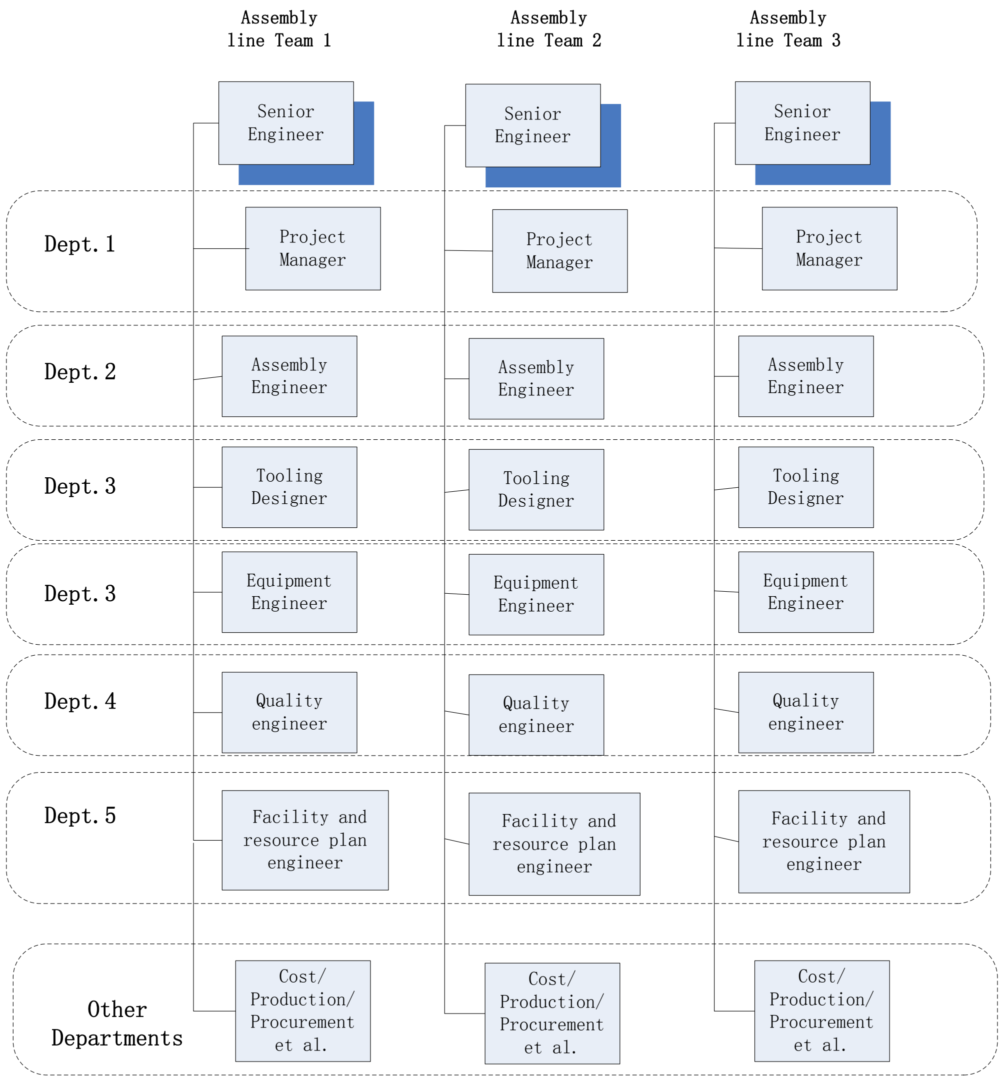


Figure 4-2 The matrix AL design team

Like most OEMs, the Tier 1 suppliers also had sub-suppliers (Tier 2) and they cooperated in the AL development, e.g. a sub-contractor was responsible for designing and building the robot system in AL. For SAMC, the Tier 1 supplier was the solution integrator and final deliverer of the whole assembly line. Though the SAMC team had to collaborate with Tier 2 suppliers on some critical equipment and technologies, it did not change the principle that the final solution was the responsibility of the Tier 1 supplier.

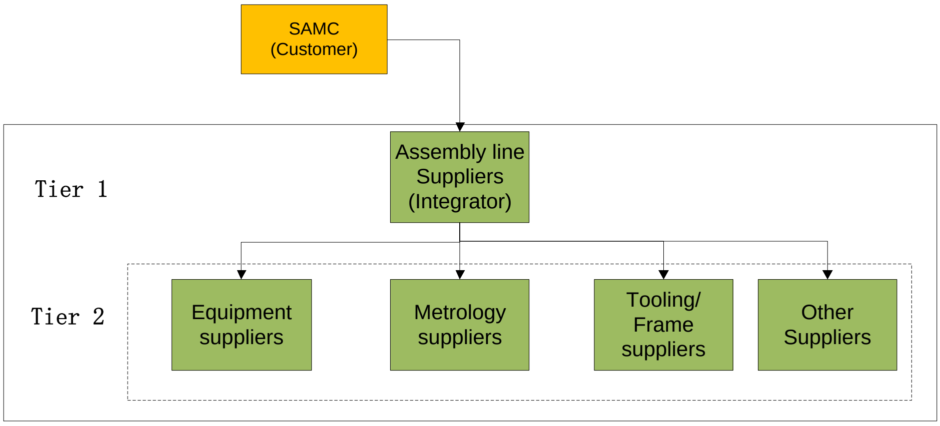


Figure 4-3 The conceptual supply chain structure in AL project

The supplier design teams had corresponding roles with the SAMC team. But the discipline classification in each supplier team was not exactly the same as in SAMC. For example, it was found that the work of the supplier Metrology Engineer, who is responsible for analysing the tolerance of tooling and providing the measuring method, partly overlaps with the work of assembly engineering, tooling engineering and quality engineer in the SAMC team. Moreover, the cooperation between Tier 1 supplier and Tier 2 suppliers were more diverse and difficult to capture, therefore the perspective of the supplier as one whole entity was taken.

Table 4-2 An idealised roles list in the supplier team

No.	Role	Responsibility in Assembly Line development
1	Project manager of assembly line(AL)	Define the project scope/ scheduling/check work progress
2	Assembly engineer	1.Joint-design assembly plan/resource plan with SAMC 2.Manufacturablity Amassment
3	Tooling designer	Tooling design
4	Equipment engineer	Equipment design
5	Metrology engineer	1.Measurement plan 2.Tolerance analysis report
6	Facility and resource planning engineer	1.Assembly line operation simulation 2.Production capacity calculation 3.Construction specification/drawling
9	Supporting departments: Cost/Production/Procurement, et al.	Calculate/estimate cost, leading time et al. of AL.

4.2.2 The SAMC and Supplier Company context – strategy of collaboration

Although the assembly line was defined as an outsourced project that the main design and building tasks were completed by suppliers, the multi-functional team of SMAC still engaged in the whole development process to ensure that the solution can meet project goals. Key factors included production rate, feasibility, technology advantage, and leading time and so on.

In the AL development, the team from the supplier had to analyse the up-to-date aircraft design data and optimise or change the AL solution independently. The effects of cost and lead time also need be considered. Regardless of whether or not a completed solution could be found, the work result would be sent to SAMC team on schedule to be assessed for further discussion.

Once the supplier team submitted the updated data-set to the SAMC team, the corresponding people from SAMC assessed the solution and decided whether or not to approve it. A solution could be put into the AL design data only when approved by both teams. If there were critical issues over which SAMC and supplier could not reach consent within the team level, the problem would be escalated to an expert panel for further evaluation.

To perform the design goals mentioned above, the SAMC team must know the design rationale, which meant not only knowing if the design was right, but also to know how and why the AL was designed in such a way and if it was the best choice. In using this co-design model, SAMC was expecting to improve its AL design ability and gain advantageous position in future programmes.

Another notable fact was that, for both the SAMC and AL teams, the project managers also have the role of controlling the data exchange activity, which gave them a holistic view of the design progress, and to be able to reduce any inconsistency of information in joint-design. To some extent, their pivot-like role avoided the potentially embarrassing situation in which the project manager loses control of the teamwork, as described by Stark (2011, p.302).

4.2.3 Technology in distributed AL design

The technology part of the AS-IS mainly related to design software, work platform, data format and storage medium, and communication tools. These were regarded as cornerstones of the concurrent/collaborative PD. Work practice and technologies affect each other reciprocally, e.g. the artefact of work process could probably affect the solution choice of group work platform, and the PDM solution may decide the data transferring route. Hence in any particular case, the wider background must be considered for analysis of technologies.

The main data types, formats, storage medium and transferring route utilised in SAMC AL projects were listed in Appendix A. More information could be found from sections below.

4.2.4 Design tools and data formats

There were more than 30 types of documents as vehicles for design data, definition, and specification of assembly line in the Detail Design phase. Some significant attributes of technology application were noticed.

For product design, both aircraft and assembly line design used CATIA V5 and AutoCAD 2007 software, and other documents were generated with Microsoft Office 2003 and Adobe PDF. There were few troubles caused by the format of data transfer in this project. The STEP and IGES format of A/C design models that could be generated from CATIA were also used.

Besides the CAD/CAM models to represent product information, team members also employed documents based on MS Office 2003 and Adobe software such as .doc, .ppt, .xls and .pdf as information carrier. Those documents were normally made up with text, photos, tables and figures. People used such documents to consolidate proposals, design knowledge, questions, decisions and plans. This paperwork took up the majority of their daily activities and constituted the main work result.

Normally, for each data/document in teamwork, a role/discipline was assigned to update and transfer it to the design process. Other disciplines provided information and judgement in the joint design process.

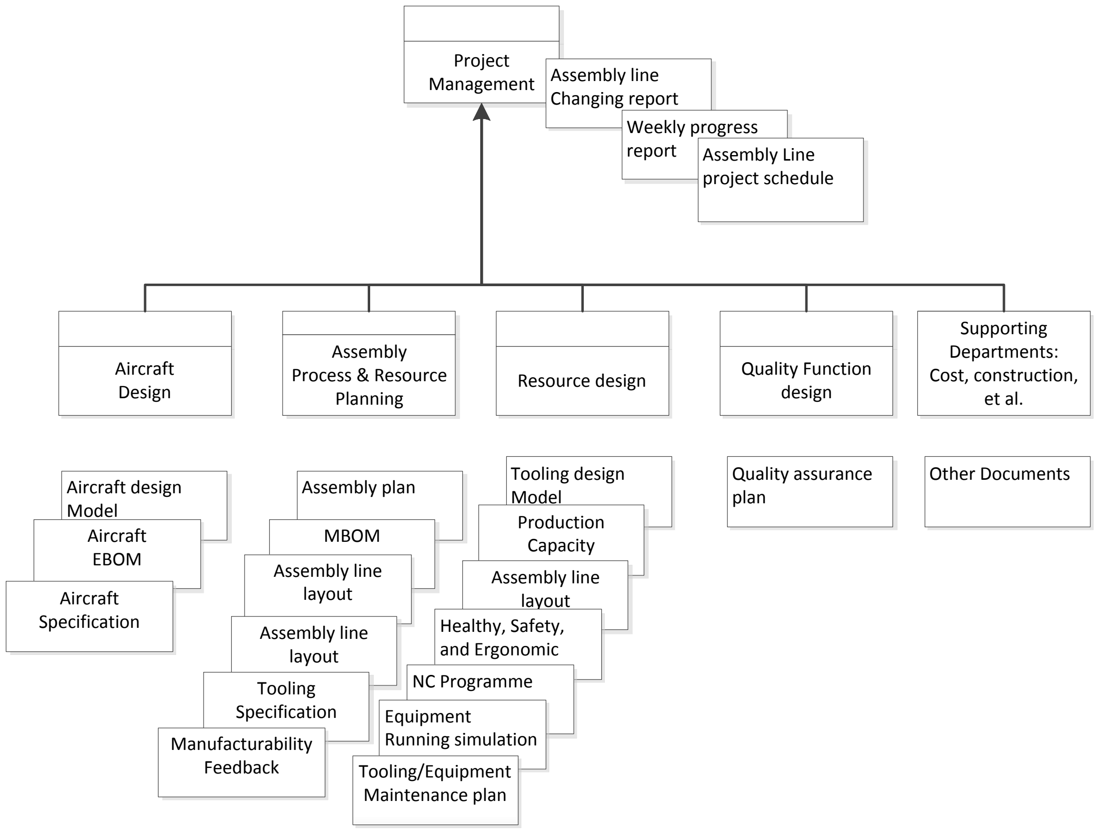


Figure 4-4 The generic relationship of main disciplines and data/documents in AL development

4.2.5 Data repository

From Appendix A, although there were many available technologies for collaboration in the current market (see Section 2.4), SAMC had not established a common work platform with the A/C design centre SADRI and AL suppliers. A PDM platform had been set up between SADRI and SAMC which enabled the A/C data to be shared. For suppliers, they used PDM or other ICT tools of their own to develop the assembly line products, but those facilities had not been integrated with SAMC at the start stage of the AL project. Hence, AL design teams had to store design data on separated systems and local work station.

The A/C data, including the aircraft design models and specification documents were originally stored on PDM (PTC Windchill system), which the A/C designer and SAMC team could access. For the supplier team, they only obtained A/C data released from the SAMC team and deposited them on their own platform or local PCs. Similarly the majority of the AL design models and documents were stored dispersedly both on SAMC and supplier team member's local PC. Some AL data, e.g. AL design models, were also deposited on FTP servers for long distance sharing.

Another issue of the data repository was the requirement of dynamic management. Apparently, neither the A/C nor the AL design was complete in the Detail Design phase. Therefore configuration management was different from the production phase in that the product data was frozen and formally released.

The aircraft design model was updated and released several times in the Detail Design phase and took the rule of "only the latest is valid." Normally, the latest design data was available on the PDM system for the SADRI and SAMC team. But for supplier use, an assigned SAMC team member (assembly engineer) was responsible to download the data set, package and name it with the release date (e.g. "HTP Model-2013-7-15"), then transfer it to supplier team via the project manager.

Similarly, regarding the AL design data, originally it was stored on the PDM or PC locally in the supplier companies, but the SAMC team was not able to access them. Hence, the SAMC team had to obtain the AL design data from the supplier team manager, and the AL data used the same rule to distinguish the latest version as the A/C design model.

Stored in dispersed systems and desktops, the versions of AL data/documents were quite independent and need to be managed manually, despite some of them having strong coupling relationship. SAMC documents passed in the milestone review meetings would be released with alphabetic version marks, e.g. "Assembly Plan, Version C, 2013-6-01 released". Figure 4-5 helps to clarify the version rule implemented in the AL projects.

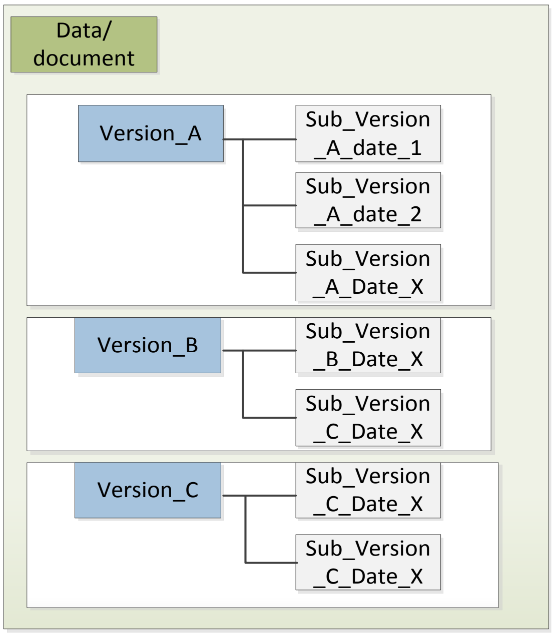


Figure 4-5 Data/document version rule in AL

The updating actions of AL design documents could be quite frequent; for instance, the NC programming task might produce new programme version weekly, and the project plan were continuously updated. To avoid using the wrong data and confusions, all members need to strictly follow the data version rule in the manual data management system and extra labour was employed.

4.2.6 Data exchange and Communication tools

As referred, there was a PDM platform for sharing aircraft design data between SADRI (A/C design centre) and SAMC (manufacturing centre). However, in the AL project, teams were not so fortunate to own such a common work platform to share data.

In the AL design, the SMAC team had to download and package A/C design data to the supplier team. For other data like assembly line tooling/jig models and documents, depending on the size of the package, they were transferred via methods such as E-mail, movable memory disk or FTP.

Table 4-3 The transfer medium of AL data

Transferring Medium	Type
Movable memory	Large volume data
E-mail	Low volume documents (less than 10 Mb)
FTP	Large volume data

Generally, the product design process involved continuous discussion and negotiation between team members. Referring to Figure 2-8, the communication method in SAMC is listed in the table below:

Table 4-4 The major communication method in SAMC AL project

Communication method	Temporal	Spatial
Face-to face meetings and discussion	Synchronous	Locally
E-mail	Asynchronous	Distributed

For collocation (same-site) work, face-to-face meeting was the most common method, but because there were no collaborative platform, information was not published on physical or virtual bulletin. Also the supplier and SAMC team members had to travel for collocated working. In this geographically distributed collaboration, E-mail was the main method for team members to exchange ideas and small size documents. Large volume data exchange required movable memory, which cost time and money, and reduced the ability of quick response.

SAMC and supplier also used FTP for transferring large size data package, but it was not as efficient as they want. There were two main reasons:

(1) SAMC required strict security policy to ensure that only authorised people were able to access and exchange information with the supplier via the Internet. Work stations were physically separated for intranet and internet which caused issues regarding data sharing and communication.

Nevertheless, the project leader had to spend extra effort to collect, receive and distribute data.

(2) The internet bandwidth was limited and large data packages like new AL design model needed hours to upload or download. If the process was interrupt, the data upload or download would need to be repeated.

Some remote communication tools like video conferencing were not used, partly due to reasons such as unsuccessful experience in previous projects and language barriers. The bandwidth of the internet was also a constraint.

4.2.7 Work process of Joint-design

In the Detail Design phase, the assembly line design maturity gradually increased with the aircraft design. The aircraft design itself was a multi-discipline collaborative project. In SADRI, structure, systems, strength, and other disciplines accomplished aircraft model in multiple loops, but the internal design activities of A/C are not in this research scope.

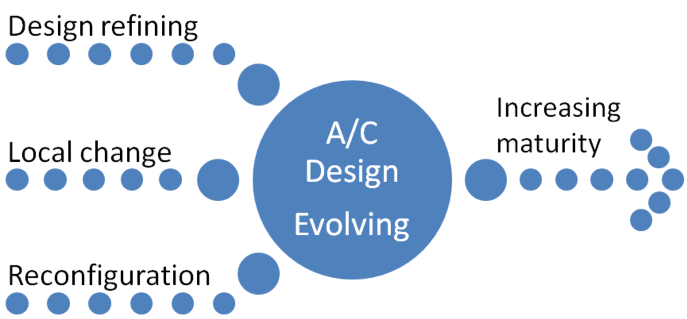


Figure 4-6 The A/C design perfecting process

The complete view of a typical AL design loop of SAMC and supplier teams is in Appendix B, which was drawn using the *Activity-based methodologies* process modelling method from Georgakopoulos et al. (1995). In the execution of each A/C design change, the workflow could be broken down to a lower level.

Although the A/C and AL data were constantly changing, there was no institution like CCB (Change Control Board) to manage the design changes as in the production stage. In fact, the AL design team was the executor of the design change and project manager took the responsibility to monitor the implementation.

By using the concept of design change pattern in PD (see Section 2.2.1), there were three typical models in the SAMC-supplier joint-design practice which affect aircraft data modification:

1. No aircraft data updated

Aircraft designers normally needed a relatively long time loop for updates, maybe a month, thus the assembly line design teams would carry on working on the AL design without new input in this period. The supplier team would elaborate the AL design and send the result weekly to the SAMC team for checking and discussion. If approval was received then the supplier team would progress according to schedule. If not, the disputed items would be added into the project schedule and more work will be undertaken.

2. Aircraft data updated without or limited reconfiguration change

Reconfiguration or changing the initial design intention would cause unpredictable impact for the AL design. Normally in the Detail Design phase, the reconfiguration happened locally in some parts of the component, for instance, changing the material, size or tolerance in a particular feature.

The SAMC AL design team had to identify all the changes of a new A/C model and then send the new A/C data to the supplier team with a brief change report. The supplier would update the original design and send it to SAMC. If there were any design changes of AL caused by SADRI that exceeded the cost or time tolerance, for example two weeks delay or 10,000 Euros extra cost, the impact would be assessed and submitted to the PM. Normally such changes were under the framework of the contract terms and senior level leaders would not be involved.

In the design process or solution finding process, a decision making sequence was followed. Each discipline in AL design needed input data to update their work, and then their solutions were forwarded to downstream. The overall sequence seemed multi-optional but was actually a single direct path. As shown in Figure 4-7, if the downstream step did not approve the input, the workflow would be suspended and the disciplines had to work together by discussion or negotiate until they agreed acceptable solutions.

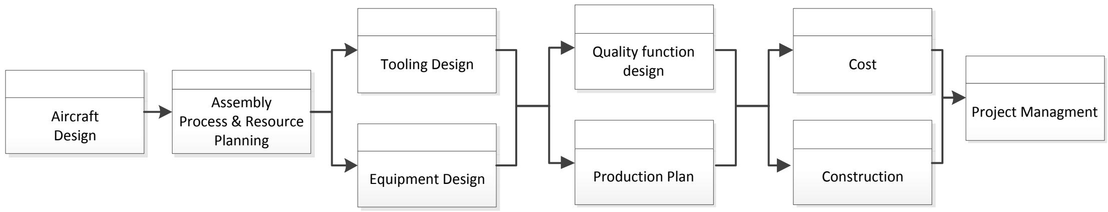


Figure 4-7 The single direction view of the design process in AL

3. Aircraft data updated that required significant reconfiguration of AL design

Although it was very uncommon in the detailed design phase that the aircraft design required a large reconfiguration, such as a composite wing-box becomes a metallic one, but it did happen. In such a case the affected area of the assembly line would be carefully checked by both SAMC and the suppliers. New solutions would be found, the time and cost loss would be calculated. Then the new solution would be assessed in a special meeting for against approval. The business contract terms might also be modified by re-negotiation between SAMC and the suppliers.

4.2.8 Data transfer in design process

From the collaboration context reported in 4.1.1 to 4.1.4, the data flow in the assembly line design process could be elaborated. The dataflow could be regarded as the synthetic result of organisation, technology and work process.

Overall, the information exchange in AL design could be divided into two levels. The macro level was about the information flow among organisations, meaning aircraft designer, SAMC AL team and the Tier 1 supplier in the AL team. Information was exchanged between Tier 1 and Tier 2 suppliers, and communication also happened between the AL related people in other SAMC departments, which was also important. However, due to time limitations, this research only focuses on the three entities in AL development.

In this case, the aircraft data was transferred via SAMC. The supplier was not allowed to obtain A/C data from SADRI. It is the responsibility of the SAMC team to confirm and feedback DFA or manufacturability issues in A/C design to the aircraft designers, which is shown in Appendix B.

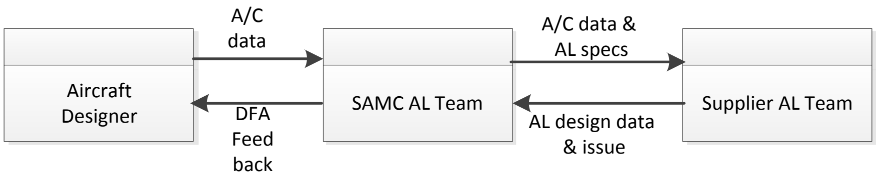


Figure 4-8 The macro level information flow in AL joint-design

At the detail level, information exchange and communication happened in the individual joint design activities. It was observed that each discipline has limited inputs and outputs for his/her tasks, thus the upstream and downstream relationship was not difficult to identify(see Appendix C & D). Furthermore, the workflow in AL design could be broken down easily.

As shown in Figure 4-9, the aircraft designer changed the design model which affected the original assembly plan. Then, the tooling design needed to be modified. The cost engineer could estimate the cost of tooling increased; the final result would be sent to the project manager for decision. In the case of such a very simple process, the input and output could be listed in Table 4-3. Input information is contained in specialised data/document for each design domain and the relationship based on document is mapped out for the workflow design based on Appendix B.

In this instance, the cost engineer needed not to understand the assembly plan. The information contained in the assembly plan did not directly converted to effective cost knowledge; hence the information flow could not be overlapped in the design sequence. The process of feedback also followed the same rule. The project/team manager was responsible to observe the design status and needed comprehensive information from all relevant parties.

Figure 4-9 The pattern of information flow between disciplines

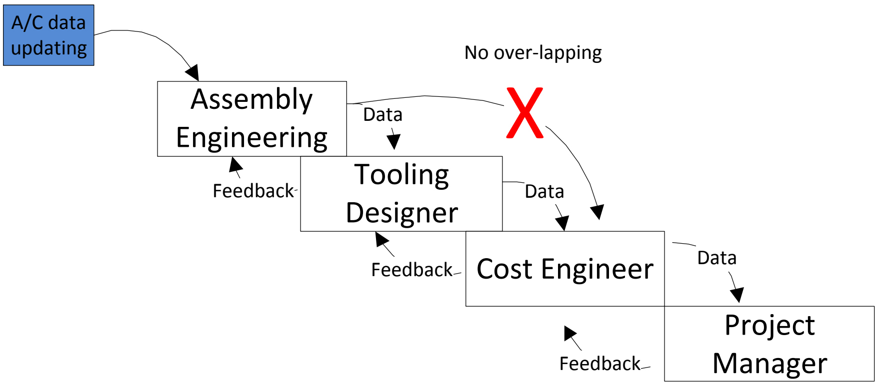


Table 4-5 The output and input in the example

Role	Input	Output
Aircraft designer	-	A/C design data
Assembly Engineer	A/C design data	Assembly plan, Tooling Specification
Tooling Designer	Assembly plan, Tooling Specification	Tooling design model
Cost Engineer	Tooling design model	Tooling Change Cost Report
Project Manager	Assembly plan, Tooling Specification, Tooling Change Cost Report	Project Schedule, Weekly project report

From the analysis it was evident that the workflow and dataflow followed a sequential pattern and overlapping engagement for all participants was not feasible. For a single team member, the work process of revising a single document or data was:

1. Receive data
2. Analyse data to know the effects
3. Revise old data or create new data
4. Submit data to next user for review or as work input.

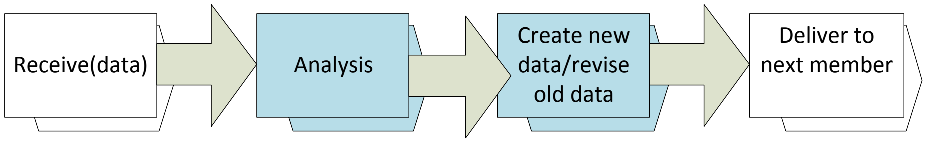


Figure 4-10 The individual activity in a single task in AL project

However in practice, the workflow at personal level was a combination of mixed *pooled*, *sequential* and *reciprocal* tasks (Fleischer & Liker, 1997). Because a data/document proceeding to finished would be the input for the downstream discipline where the content may not be fully appreciated, there may be a period of justification, negotiation and revision of specifications in data/document between two or more members. The upstream discipline tended to send a draft to downstream members and until they reach consent, the content would not be finalised and formally released. The data exchange and update frequency could be very high between two strongly linked disciplines (see Appendix C & D). Moreover, when the affected scope was spread to more disciplines, the whole loop was also extended. In such a situation, blended communication acts of *handover* and *joint design* were happening everywhere (Eckert et al. 2005, p.243).

When it was necessary to resolve a complex issue in AL development, a team manager would request a special conference the relevant disciplines or organisations.

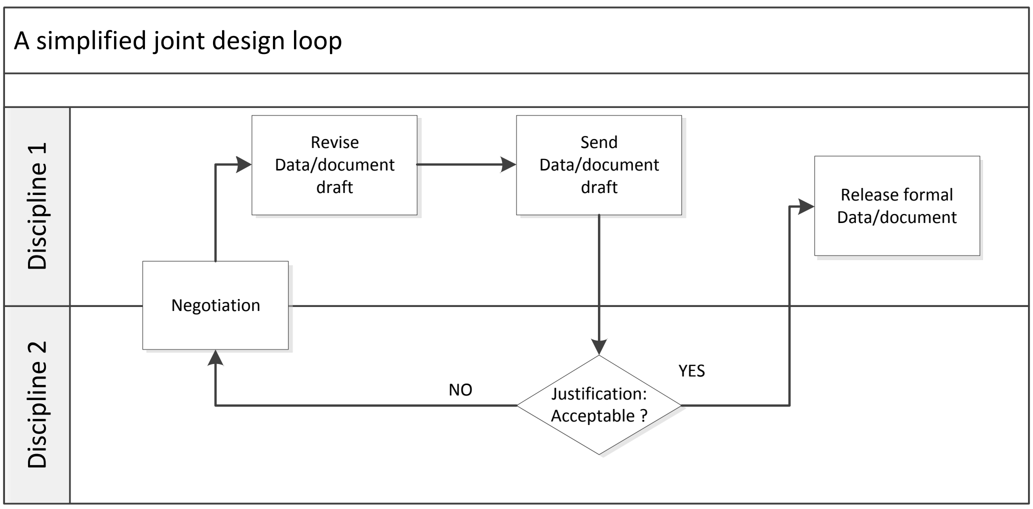


Figure 4-11 The data/document review loop

For an explanation of task independence and communication matrix, see Appendix C and Appendix D.

4.3 Assessment of AS-IS

4.3.1 Theory matching & benchmarking

From the literature review, three attributes of concurrent engineering were noted: parallel workflow, multi-discipline team cooperation and utilising integrated information tools. It was difficult to gain quantitative data and be able to compare with theoretical metrics or benchmarks. A more practical way was to check the elements in the SAMC AL projects practice against CE principles and industry practice.

In the SAMC AL projects, cross-functional development teams, on both customer and supplier sides, were established and worked with the support of functional departments. The cooperation model between SAMC and suppliers was also a logical industry practice.

The next part was to check the concurrency of work process. The work process in this case could be described by breaking it down to multi-level workflows, which in top-to-bottom way were:

1. At aircraft project level, the assembly line was developed in parallel to the A/C design;
2. In the assembly line project, customer (SMAC) and supplier worked simultaneously to find a solution.
3. In a single design loop, partial or locally joint designs among disciplines happened in the overall sequential workflow.

Table 4-6 shows three main works concerning concurrent engineering implementation in Boeing and Airbus. Obviously, the number of works reporting the CE work process and flow in such two aerospace giants is limited; hence this comparison is limited in coverage and timing.

Table 4-6 Benchmarks selected for work process

Key Words or title	Organisation	Source
The Boeing 777: Development Life Cycle Follows Artifact	Boeing	Jørgensen et al., 2007
concurrent engineering, processes, methods, design, aeronautics	Airbus	Pardessus, 2004
Collaborative Engineering, iDMU, Concurrent Engineering, DMU	Airbus	Mas et al., 2013

In the case of the B777, Jørgensen argues that in the B777 programme, the combined over-all waterfall and locally iterative develop process was actually adopted, similar to the practice used in SAMC.

In the case of ACE (Airbus Concurrent Engineering) according to the report by Pardessus (2004), the aircraft were developed in parallel with the development process of the industrialisation (e.g. tooling). A later work indicates that the ACE applied in previous projects still encountered problems between aircraft design and manufacturing disciplines in data sharing, such as "The current deliverable is the product DMU and compact disk or memory sticks flies over the wall instead of drawings," which weakened the effect of CE. Hence, the measure of improvement was to introduce collaborative engineering and to update the DMU to iDMU that provided an integrated work environment. Such phenomena were also happening in the SAMC AL project. Finally, in Airbus, a new collaborative function model *(Figure 5)* was used to define the conceptual work process to achieve higher integration among main disciplines (Mas et al., 2013).

From this short benchmarking, there were no suggestions that the concurrency of workflow in SAMC AL projects have significant disadvantages compared to the top two industry peers.

The third part was to check the technology that supported the work activities of CE. Fortunately, more research works was found referring to this topic related to Airbus or Boeing, as listed in Table 4-7.

Table 4-7 Benchmarks selected for technology assessment

Key Words or title	Organisation About	Source
The Boeing 777: Development Life Cycle Follows Artifact	Boeing	Jørgensen, 2007
PLM: Boeing's Dream, Airbus' Nightmare	Boeing and Airbus	Bartholomew, 2007
Managing a global partnership model: lessons from the Boeing 787 'Dreamliner' program"	Boeing	Kothaand Srikanth,2013
concurrent engineering, processes, methods, design, aeronautics	Airbus	Pardessus, 2004
Collaborative Engineering, iDMU, Concurrent Engineering, DMU	Airbus	Mas et al., 2013
Enhancement of product information collaboration and access in the aerospace industry	Airbus	Shehab, et al. 2013

In the development of B777, the CAD based pre-assembly technology was used to detect possible design faults before the actual assembly work (Jørgensen, 2007). In the later model B787, the effect of PLM, which was mainly integrated with the Dassault CAD/CAM/PDM solution, was advocated (Bartholomew, 2007). Even so, Boeing still experienced the problem of coordination and data sharing in collaboration with global partners, and the PIC (Production Integration Centre) was built to provide enhanced visibility and project management. From the report, the project delay recorded showed how frustrations were experienced in the process of integrating with global suppliers in the B787 programme (Kotha & Srikanth, 2013).

In Airbus, PDM and CAD based DMU technology was applied with ACE since the mid-1990s in the A380, A400M and other programmes. The DMU technology essentially was a Virtual Reality tool; it also enabled the management of product configuration, knowledge and manufacturing process in an integrated way (Pardessus, 2004). However, in later development, the DMU was developed to iDMU, which relied heavily on using PLM tools to improve the manufacturing execution ability for the shop floor, and promote the information sharing for participants (Mas et al., 2013). To improve the efficiency of data exchange between OEM and the Tier 1 suppliers, the PTC PDMLink and Microsoft SharePoint based ICT tool was proposed by Shehab, et al. (2013).

In the SAMC AL project, a number of CAD/CAM and ICT tools were employed, which can be found in Appendix B and are separately listed in Table 4-8.

Table 4-8 The Software/ICT tools used in SAMC AL project

Software/tool	Category	User
CATIA(Dassult)	CAE	SADRI, SAMC, supplier
Delmia(Dassult)	CAM	SAMC, supplier
AutoCAD(AutoDesk)	CAD	SAMC, supplier
Windchill(PTC)	PDM	SADRI, SAMC
FTP	Shareware	SAMC, supplier
E-mail	Shareware	SADRI, SAMC, supplier

From this table and the AS-IS data in Section 4.2.3, two major and urgent issues were identified:

1. Software integration

2. ICT tools for data exchange

These two issues were caused by CAD/CAM tools being deployed in a stand-alone way in SAMC, and the wall between organisations had not been entirely removed. The design facilities for CAD/CAM had not been fused to a unified network for all participants in PD, hence bringing problems such as:

(1) Only aircraft data is stored on PDM (Windchill system) and could be shared by SADRI and SAMC. The AL design data and activities were dispersed on PC locally in SAMC and suppliers. Each discipline used their own software to complete their design task, e.g. the assembly planner could run the AL simulation with the A/C and AL design models, as discussed by Meerkamm and Koch (2005, p.314), but eventually they

have to demonstrate problems found in product design to both A/C and AL designers, which was the goal of team work to correct the design at an early stage. If all team members worked at the same site, it might be not a significant problem, but in the case of the SAMC AL project, the A/C design team, the SAMC team and supplier team were geographically separated, which suffered an invisible wall regarding communication.

(2) Lacking of integrated work platform for SAMC and suppliers to store A/C and AL product data in a structured way made the configuration and data/document version management a labour intensive task for all participants. It also increased the risk of using out-of-date data among design members.

(3) Without the centralised data vault, the traceability for historical design data in AL development process was a challenge, which was crucial to capture design rationale and archiving in case of possible future disputes.

(4) To manage the continuous design changes, entangled cross organisation activities and to meet the project goals constituted a tremendous challenge. Holistic and up-to-date schedules were needed to help team members and managers to face the rapidly shifting design environment. However, the worksheet-based (Using Microsoft Project or EXCEL software) project information system was unable to respond to such a requirement.

(5) The data exchange between SAMC and supplier by using E-mail, FTP and memory sticks were not efficient. The frequency of AL design models exchange was limited due to the time needed to post memory sticks. Meanwhile, FTP did not satisfy the security requirements and was limited by internet traffic bandwidth. Furthermore, even though the AL design data had been obtained from the supplier, the project manager in SAMC had to distribute it manually.

Overall, this cumbersome situation was caused by the failure to construct an effective supporting information platform. This status is described by Stark (2011, Chapter 16) as the “pre-PLM” environment, and can also be found in the white paper of the Original Equipment Supplier Association cited by McClellan

(2002, pp.67-69) that primary elements need to be improved in a collaborative product development.

4.3.2 Summary of AS-IS

In the AL project of SAMC, two elements of CE (the parallel development of product workflow and the multifunction team work) were realised in practice. The design process of A/C and AL carried on simultaneously, and most jobs were conducted by joint effort from cross-discipline teams.

As this was the first time to run such a large scale project, SAMC had neither the time nor the budget to invest heavily on constructing the dedicated platform to support the development work. By using an existing work environment (PDM, intranet and internet) and software (Microsoft Office, Dassault Systemes CATIA, and Adobe PDF et al.), engineering data exchange and communication function at a basic level. Therefore, the effectiveness of concurrent workflow in AL development was limited and the project management people found that they were not able to control the design process at the detail level. The net effect of this situation resulted in longer overall development cycle and higher cost.

Compared to benchmarks like Boeing and Airbus, which have experienced similar issues in previous years, SAMC needs to improve the current CE performance by improving management process and PD tools.

5 Proposed solution, mock-up & validation

5.1 Proposed TO-BE

5.1.1 Identify improvement opportunity

Improvement opportunities were identified based on the investigation, description and assessment of the AS-IS. This chapter focuses on finding an appropriate solution for the SAMC assembly line projects (TO-BE). The roadmap is:

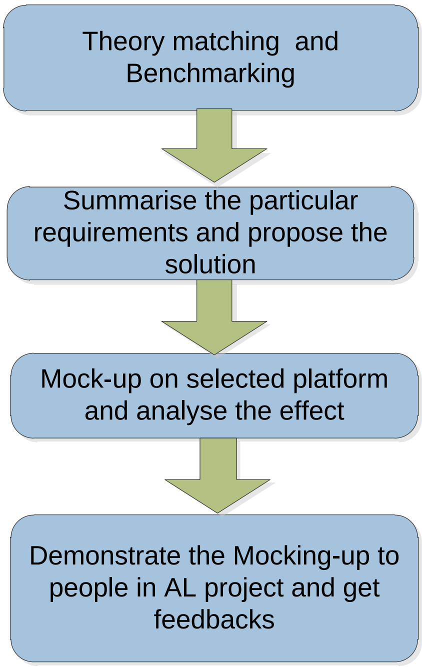


Figure 5-1 The roadmap of TO-BE

The assessment of AS-IS highlighted the main weakness of CE implementation in the SAMC AL project was the lack of an integrated solution to support data management, information exchange and dynamic workflow. Such a situation was also experienced by benchmarks in the CE deployment (Boeing and Airbus, see Section 2.4). Therefore their solution could provide valuable reference. The particular context of SAMC should also be considered to elaborate the requirements of systems.

5.1.2 Proposed solutions

To find the integrated solution, four elements of CE context: *People, Organization, Technology and Strategy* must be considered, these had been indicated in section 4.1.1. The improvement opportunities from them were explored.

The CE practice could be expressed as people from different organisations (teams, departments and companies) work synchronously under constraints and pre-defined rules (strategy) to meet goals by using available technology. As found and discussed in Chapter 4, people from SADRI, SAMC and supplier in the joint design project of AL collaborated in a CE way.

Surely the people from SAMC and other organisations could be further trained to save time and labour on negotiation and data transfer, and report more efficiently to project managers. However, the uncertainness of PD and ad hoc activities are characteristics of such a large scale, distributed collaborative project, people measures only would likely to cause more paper work and conflicts, if not confusion.

Another approach to resolve information sharing in PD was by creating common work folders on the network, as people in SAMC had tried. But even though the work teams could obtain data from the shared folders, the workflow in AL development would still be an issue for project management. If people could not work with clear workflow and interact with data derived from the iterative development, the situation could degenerate into total chaos, which had been the experience in previous projects.

Past practices and research work, especially of the aerospace industry leaders Boeing and Airbus, had used PLM as the main tool to facilitate their global PD collaboration, as found in chapter 2. In the case of the SAMC complicated product of aircraft and assembly line with enormous data and workflow to be managed (see Appendix A & B), adopting PDM/PLM/ICT tools to build integrated global collaborative environments could be an effective way.

As claimed by Stark(2011, p.8), '*PLM joins up many previously separate and independent processes, disciplines, functions and applications'.* It is a method to connect isolated islands in PD and rebuild the work process and organisation structure, to support CE. PLM also could help people from different levels to get a holistic view, and help the people in PD to achieve their goals.

PDM, which aims to manage the dispersed data and dynamic workflow, is the core modular of PLM system (Stark, 2011, Chapter 10). In the AL detail design phase, the primary function of the design platform is that all users should be able to access product data/design documents easily rather than with tedious manual handling. Hence, to speed the design efficiency and reduce labour cost, a PDM based work platform was proposed to provide key functions including:

1. Centralised data storage
2. Configuration management for entire design data
3. Remote data sharing and communication for collaborative design
4. Holistic and dynamic workflow management

These four elements were regarded as the kernel functions to support the concurrent/collaborative engineering for the SAMC AL project. In the next section detailed requirements and features are discussed.

5.2 Detailed feature of proposed work platform

The proposed solution was based on currently available technology. The common functions and features of PDM had been summarised in many research works, e.g. Stark (2011, Chapter 10), Lee et al. (2011). Here the particular requirements in the SAMC AL project were elaborated.

5.2.1 Distributed heterogeneous environment

The data vault is the primary function of PDM. In the case of SAMC, a PDM system had been implemented for storing and exchanging A/C design data between SADRI and SAMC. However, for AL suppliers, they had diverse PDM systems provided by different software vendors. The ideal solution would be all collaborative parties of the C919 project working on the same PLM platform. To realise this would require long term efforts and heavy investment.

It would be unrealistic to unify the collaboration systems in a short time; therefore the alternative solution would be to construct a heterogeneous environment for all the participants be a possible approach would be SAMC builds the PDM system as the data exchanging centre, and coordinates the internal and external design activities in SADRI and the supplier by interfacing workflows. The overall distributed system architecture shown in Figure 5-2 had been derived from previous work (Yang et al. 2009).

One of the distinctive characteristics of the AL project was that the internal workflows of SADRI and supplier could be treated separately, and the interface of workflow and data flow among the three parties could be designed from the AS-IS.

Current technologies which are based on STEP, XML language and CORBA protocol (Shen et al, 2013) could support the distributed PDM systems. In a global view, the PDM systems located in A/C design centre, A/C manufacturing centre, AL suppliers, constituted the building blocks for the PLM system.

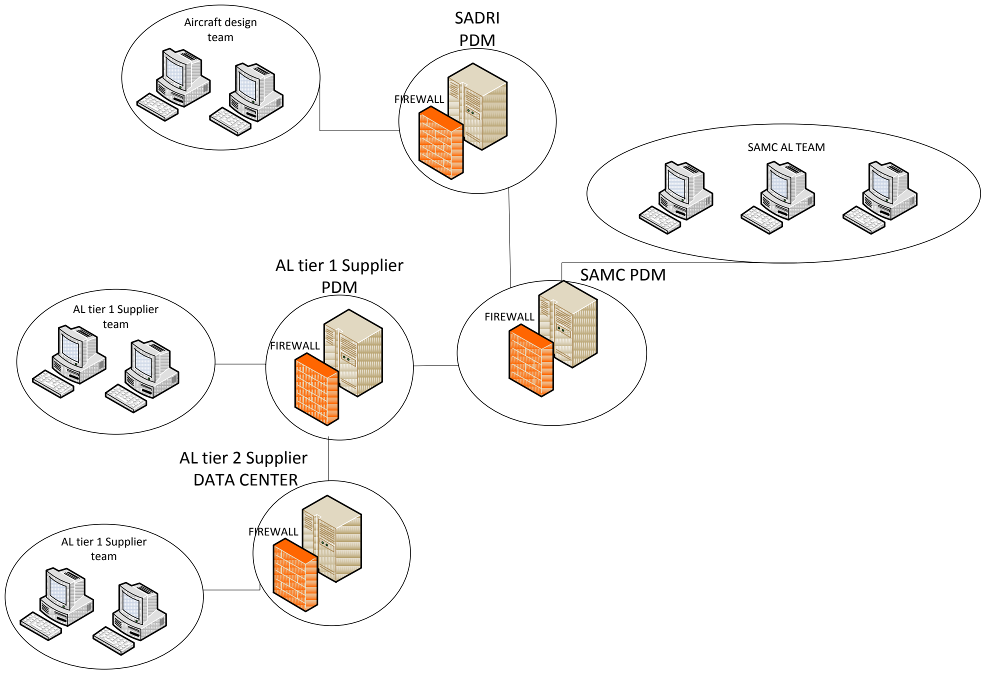


Figure 5-2 The overall architecture of PDM deployment

The PDM system in SMAC was designed as the data warehouse and intermediary site. Another feature considered was the *temporal* dimension. From the result of AS-IS, the design process does not rely on synchronised data transfer, e.g. AL designers had no requirement to operate a design model or edit documents on the platform at the same time. The separate design loops of A/C and AL data meant that data could be transferred on request. Data could be releases according to plans and the receiver informed. This matched the work convention described in Chapter 4.

5.2.2 Data repository

The data repository or information warehouse design (Stark, 2011, P.209) was discussed in many research works. In a heterogeneous environment, many mature solutions to harmonise various PDM systems could be found from the commercial market (Dassault; Siemens; PTC). The proposed solution needed to match the work convention in SAMC AL project as much as possible to reduce user resistance and training cost. Three elements were considered regarding the specific problems of the SAMC AL project.

1. User interface structure design

   The data warehouse structure design needed to link to *the user interface layer* (Jianyu et al., 2012). Considering the work convention in the Pre-PLM environment, the SAMC and supplier AL team should set up work folders for each team. Data/documents should be created as items under folders, and the access control should be pre-set by the corresponding project manager.

   The product data for both A/C and AL should be organised in a structured way for the convenience of configuration management. And all the data formats used e.g. MS .doc, .xls, pdf should be supported for online viewing and editing.

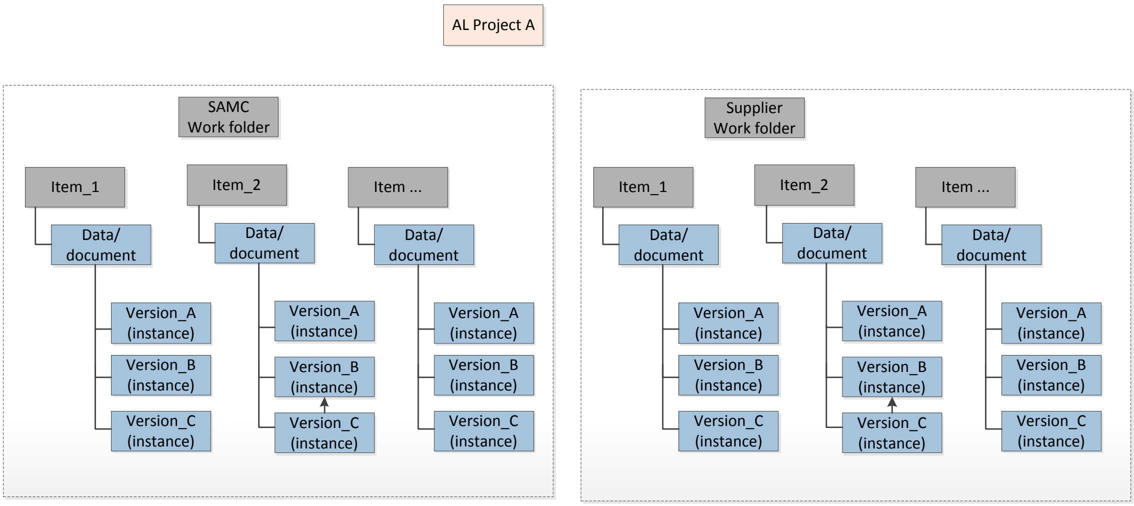


Figure 5-3 The proposed work folder structure

2. Access control

The access authorisation should be set to protect the data security, for example, setting restrictions for a particular user group to read, modify or delete design data. This also provided Intellectual Property (IP) protection for the different organisations (Stark 2011, p.117). Meanwhile, although SAMC and supplier may have different PDM systems, by using the right ICT tools, all teams should work on the same interfaces in one project rather than separated.

3. Version rule of data/document

All data or documents should have unique permanent ID and variable versions, no matter by using manual version management or data vault. There are two types of versions: master version and sub-version. The master version (e.g. version "A","B","C") should be used to identify formally approved data/documents and the sub-version (e.g. version "A_1","B_3") should be used to mark the data/document in the continuous updating of daily work. Each version should have a corresponding instance, and a Check-in/Check-out function should be provided by the system to ensure the consistency of data on the platform (Kovacs, 1999).

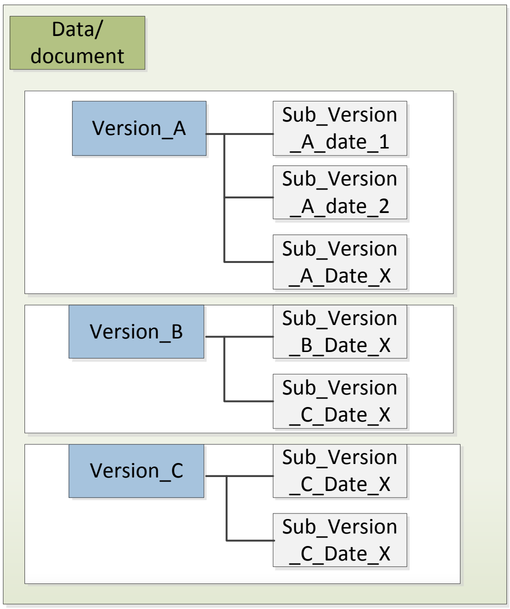


Figure 5-4 The master version and sub-version of data/document

5.3 Workflow/dataflow pattern

5.3.1 A/L design loop

As pointed out in Section 4.3.1, the design process in AL project detail phase could be broken down into 3 levels:

1. Assembly line are being developed in parallel with the aircraft;
2. SAMC and teams supplier work simultaneously in a single design loop;
3. Individual collaboration within and among teams

In a single design loop (See Figure 4-6), the workflow should be triggered by the release of a new aircraft model. Different team members/disciplines should then analyse the impact of changes from upstream and find new technical solutions, as well as elaborating the existing part with updated A/C data. The AL design change caused by engineering would be finally frozen in AL design data/documents, e.g. design model, specification, report. The circulation could last weeks and needed cross-discipline work in AL teams, as shown in the AS-IS.

The problem would be, due to the uncertainties of the engineering change, each discipline might have to analyse the input data and determine (1) the impact scope in his/her discipline; (2) how much the next discipline is to be affected. It was found that, for a single discipline, the direct upstream and downstream connections were limited, normally less than three (see Appendix B). Figure 5-5 illustrates the decision making process in the design loop.

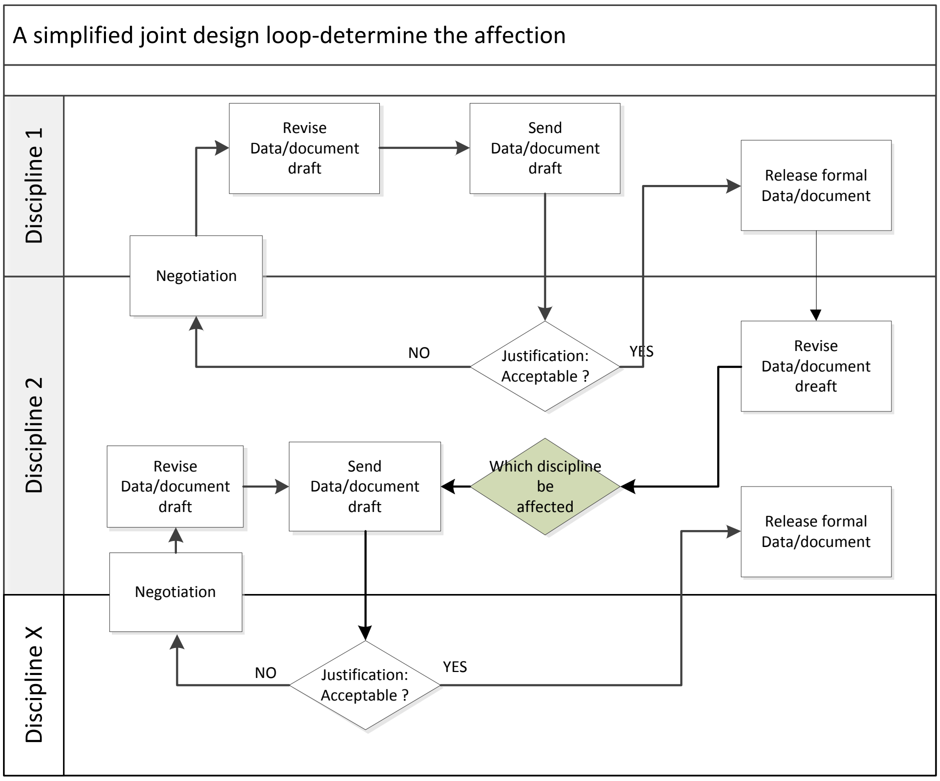


Figure 5-5 Choose the affected discipline

It was necessary to predefine the overall workflow path for such a loop, even though there were many circumstances of decision making which cause uncertainty in each design change. So in the workflow management module of the PDM, the better way was to set up a simple workflow template for each discipline role and leave the freedom of modifying.

5.3.2 Activity and tasks

Patil and Chaudhari (2002) outlined that the WFM system should have a standard definition of the work content to realise interoperability between different platforms. As indicated in the analysis in Section 5.2.1, the work platform for the SAMC AL project should be a distributed heterogeneous system, to reduce the complexity. Workflows in SADRI, SAMC and supplier could be treated separately yet connected in the PDM system of SAMC which runs as a hub. The key would be the standardisation of tasks in the collaborative process.

To build the activity-oriented model, the *task and manipulated objects* was clarified. From the AS-IS, it was seen that in most joint-design work, the focus of design, whether aircraft or assembly line, were central to data/documents because the product feature and parametric are encapsulated in product model and specification documents.

Data and document instances could be linked to workflow (Qiu and Wong (2007), and operations of data and documents constituted the activities in tasks. By the relationship of the user's activities and the document content, tasks in the AL design workflow could be categorised to three basic types, as below:

Table 5-1 The task types

Type	Meaning	Operation examples
DO	Change exist data or create data.	Create Revise
Acknowledge	Inform other members, or trigger an event of building a link between the data and the user	Notification Change ownership of item Release
Evaluate	Judge and comment the content of data, and give additional information as data reference	Review Approve Reject Choose

The result of the operation would change the status of data, e.g. publish data/document would have the status "released" and be regarded as approved as consolidated design data for another user.

The performers of each task were defined as "roles", which represent the team workers ("agents") in the real world, and the operation authorisation such as view/edit/delete would be set by the system manager (Georgakopoulos et al. 1995).

By combining the data-centric tasks, workflow could be established and modified in the start and middle of the design process to adapt to the uncertainties in the design process.

These standard tasks are used to define the workflow templates that could be associated with different data/documents and could be re-assigned to improve reusability.

5.3.3 Improve the communication in joint-design

The design work in the SAMC team was peer-to-peer. In order to improve work efficiency and concurrency, the E-mail system should be integrated into the workflow management to support informal communication. .

5.3.4 Other requirements

The product model visualisation should be implemented to give users immediate view of the product status while decomposing and reconstructing the product, as well as in tooling design and simulation.

For project management, the holistic view of workflow should be supported by the visualisation of WFM in the new platform. Connecting WFM with scheduling enabled effective control of the work progress.

5.4 Mock-up

To verify the feasibility of the proposed TO BE, the document/data structure, the organisation structure and the workflow templates were realised in the Teamcenter Engineering software, and used as the basis for validation.

5.4.1 Data for Mock-up

Due to the issue of confidentiality, the author could not use the product data and documents in the C919 programme for mock-up. To construct the AL design scenario, a light aircraft flap CAD model was used to set up the basic product structure and test the visualisation ability of process design on the platform. The use of this model is authorised by its owner (source: flap model: http://grabcad.com/library/light-aircraft-plain-flap). Other documents were created as similar to the normal files employed in the SAMC AL projects.

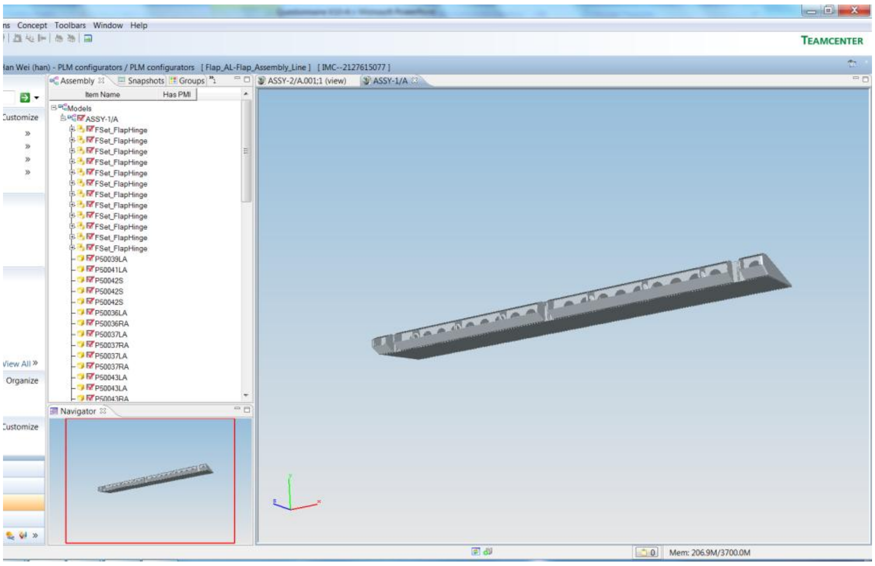


Figure 5-6 The product structure model in mock-up

5.4.2 Platform selection for mock-up

Teamcenter® is the PLM software developed by Siemens PLM Software. Its functions include:

- Design management
- Document management
- Bills of material (BOM)management
- Process execution
- Requirements management
- Manufacturing process management
- Supplier integration
- Visualisation, and so on (Siemens).

Teamcenter 8.1 supports distributed collaboration, and could be integrated with various mainstream CAD/CAM/ERP tools. It is a software widely used in engineering industry, which makes it a suitable platform to test the proposed solution in this research.

In this mock-up, it was assumed the supplier use the same software, as this would not affect the testing of workflow/dataflow model in this research.

5.4.3 Mock-up process

To simulate the daily design activity, a design update was released by the A/C designer, and triggered the consequent parallel workflows between SAMC and supplier to find the solution. The flow was drawn to run on the Teamcenter platform.

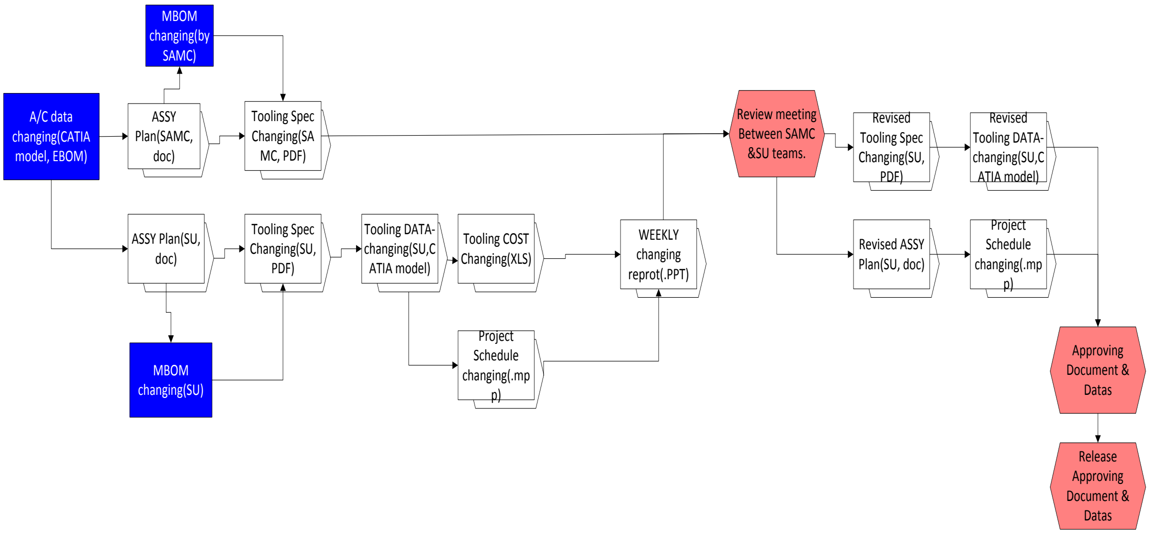


Figure 5-7 The Mock–up of AL design changing loop

On the Teamcenter platform, the mock-up process was:

1. Build the team and roles

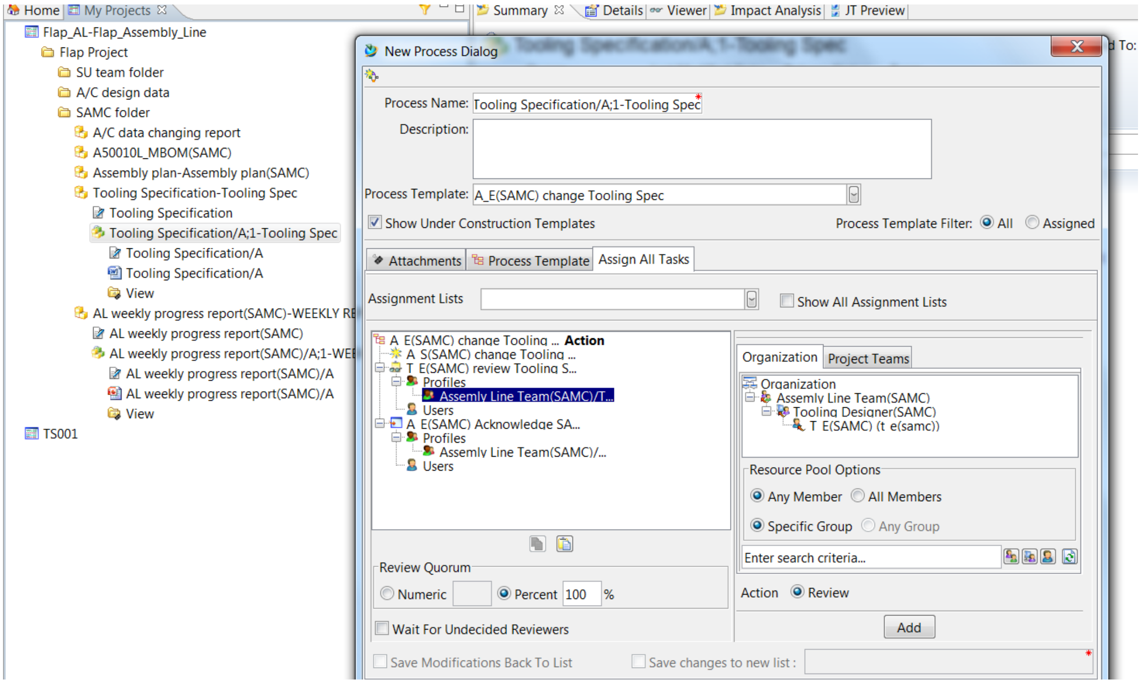


Figure 5-8 The teams and roles in Mock–up

The simulated teams and roles(disciplines) were built as in the actual AL project. Every role was given different access authority to the design data.

2. Build A/C product structure and AL product structure

   The light aircraft flap model was inputted to Teamcenter and the EBOM and MBOM were built to test the model visibility in the reconstructed product structure (see Figure 5-6). Teamcenter also showed strong support of multi-version BOM management which gives assembly planner a powerful tool. The basic BOM structure of the assembly line was also created and the jig models were inputted into Teamcentre.

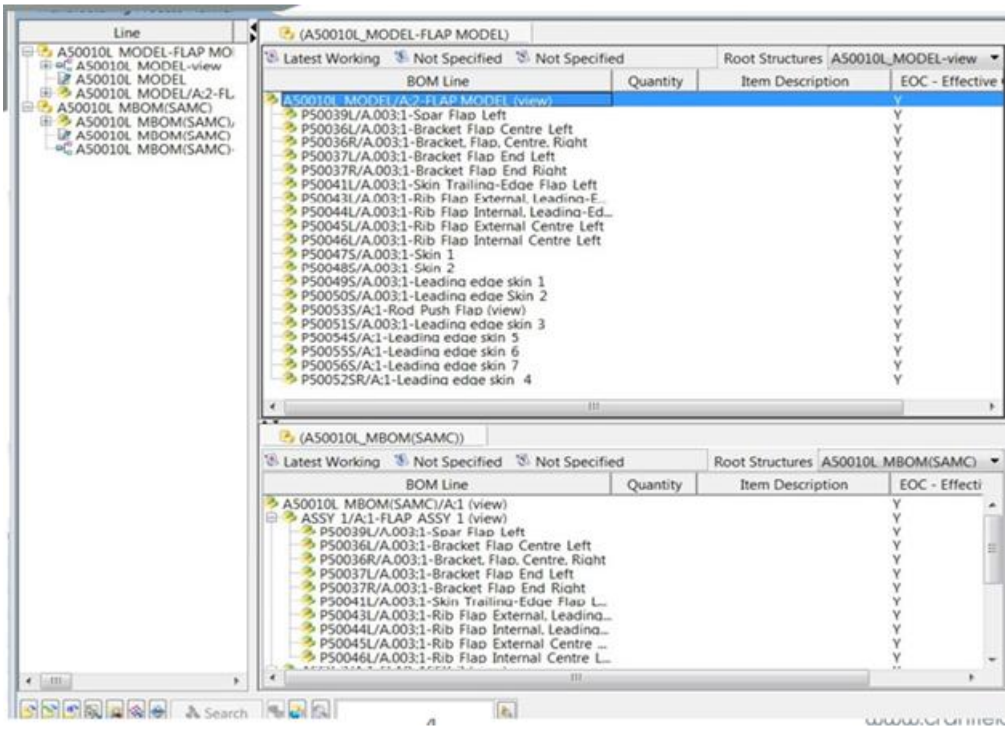


Figure 5-9 Build the EBOM and MBOM of product

3. Create documents and version management test

   Work folders for SAMC and supplier teams were built, and documents in .doc, xls, ppt and .pdf format similar to those used in AL project were create to test the compatibility of Teamcenter. Also, a key feature realised was the automatic version control of data revision. By using check in/out and revise function, the correctness of the major version and sub-version could be guaranteed in document updating process.

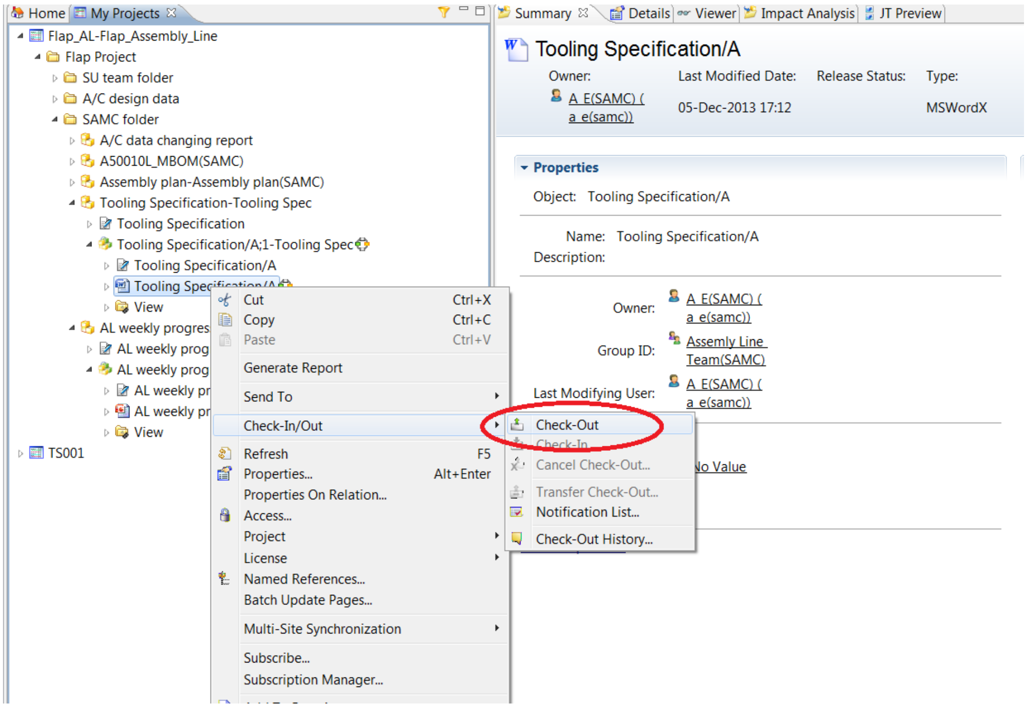


Figure 5-10 The workfolder and document check out/in in Teamcenter

4. Set workflow template

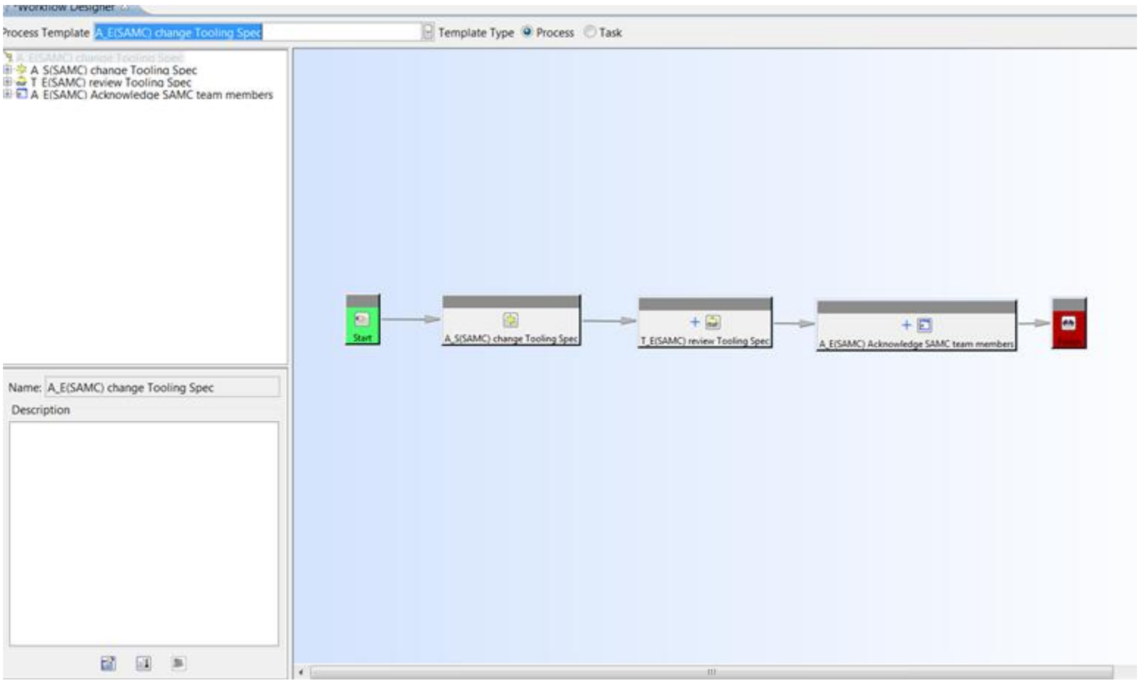


Figure 5-11 Set up workflow template on Teamcenter

The separate workflows were set up as workflow templates in Teamcenter. The data-centric work activities included were *create*, *revise* and *release* data. For a single document, the workflow template could be pre-defined and shared, also it had the flexibility of workflow change.

5. Simulate work process of AL design loop

On Teamcenter WFM, any role authorised could create and release the workflow, which gave the users great convenience. Even some functions provided by the platform were not fully exploited; the result demonstrated the feasibility of running the proposed concurrent workflow and dataflow on this mainstream PLM platform. The detailed workflow in Teamcenter was illustrated in Appendix E with the instance of changing tooling specs in SAMC team. The entire workflow comprised of around 20 data/document-centric tasks, and most of them were similar to the example in the Appendix E. To fit within the page limit of the thesis, other functions tested in Teamcenter were showed in Appendix G. Further discussion of the mock-up is in Chapter 6.

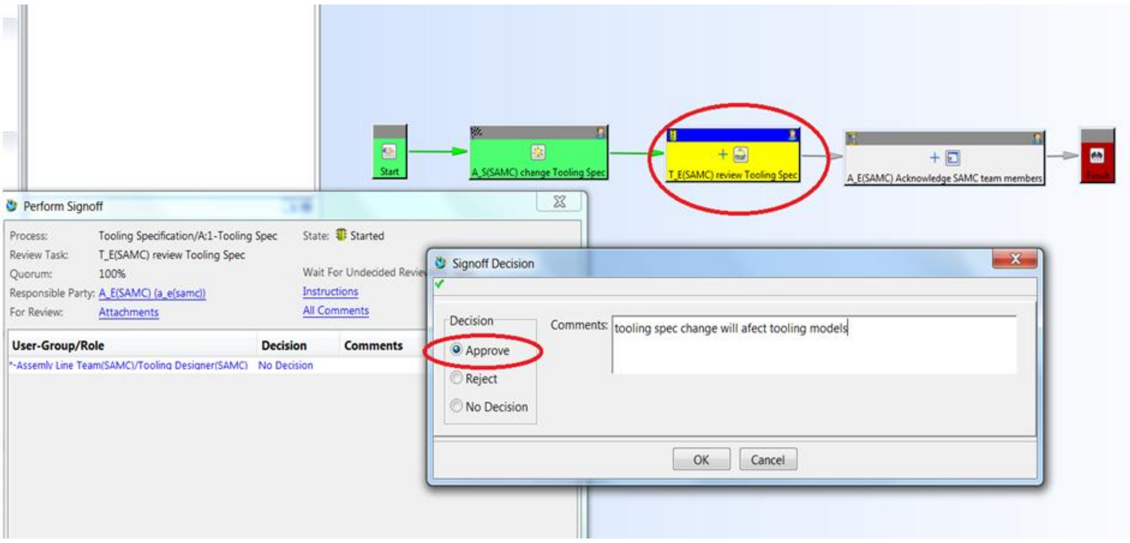


Figure 5-12 Workflow simulation on Teamcenter

The mock-up result resided on the intranet server of Cranfield University, and can be visited and demonstrated by request.

5.5 Validation of proposed solution

To validate the effectiveness of the proposed solution, a semi-structured questionnaire was conducted by the author with key persons working in the

SAMC AL projects. There were six respondents, of whom 3 were assembly engineers in SAMC, and 3 were project managers from the supplier. By the date of thesis submission, 4 of 6 questionnaires were returned.

The questionnaire had 9 questions in dual language (Chinese and English), covering the AS-IS, user expectation and validation of the proposed solution. Appendix G has the attachment to illustrate the mock-up work to the responents. For details of the questions see Appendix F. The feedback is discussed in the next chapter.

6 Discussion

6.1 The summary of the mock-up

The mock-up work on the Siemens Teamcenter 8.1 PLM software realised the basic requirement of the proposed solution. The main proposed functions of platform showing satisfaction are:

- Data/document/work folder management
- Access control of data
- Automatic version management
- Bills of material (BOM)management
- Product Visualisation
- Activity-based workflow customisation
- Dynamic workflow

The functions in mock-up appeared to reduce effort and time in transferring data in the AL design activity. In the simulation, once the data or documents were released, the target user could receive notification by E-mail and be able to access the required data from the platform. The daily revisions of data/document were supported by the automatic version control mechanism and ensured the consistency of the various data/document. The BOM management and product visualisation enabled the team member to view the product model in process planning and discussion.

By using the WFM module, the design loop could be planned and run on the platform. Not only the project manager, but also all co-workers could create and view work processed and participate at an early stage. Hence, this WFM design could give team members more control in the uncertainty of the design process. The design activities were data/document centric which enabled users to set multi-tasks like review and releasing. The user’s opinion could be recorded which improve communication in the design process, compared to single document hand over. The traceability of the decision making process could also be achieved using the platform.

However, in the Teamcenter mock-up, the WFM module had two settings that did not fully met the TO-BE design.

1. The ***revise*** operation of document/data was not listed in the workflow module, this necessitated the user to operate it separately from the workflow module. This weakened the connection between data and operation in WFM.
2. Each single workflow could only reference one object or object set. In a real process, the uncertainty in the design loop would require the user to point to multiple affected data/documents that the downstream user need to work on. The impact of this setting in Teamcenter 8.1 was to make it impossible to maintain the continuity of the work flow in one template. The workflow would instead be divided into file-centric review segments, which are connected by notifications to people to start their task and notify others when they made their judgments.

The test result verified the argument of Merminod and Blanco (2008) in the report about implementing Teamcenter in an enterprise. The workflow management of Teamcenter could still be further improved.

The latest version of Teamcenter is 10. However, this was not available for this research. The improvement to WFM regarding those two points was not found in the official introductions (Siemens). Due to limitations of time and resource, the WFM function of other well–known PLM/PDM solutions such as Dassault ENOVIA and PTC PLM were not studied and tested.

6.2 The feedback questionnaire

Four persons completed the semi structured questionnaire by the date of thesis submission. The results were shown below. To be concise, the corresponding Chinese language parts of the questions were deleted.

Question 1:

To what extend do you agree such an expression: in the assembly line detail design phase, the majority design work is comprised of data creating/revising, as well as work result consolidated into various documents? (5=Very much, 3=Somewhat, 1=Very little, please remark with number 1,2,3,4,5)

The answers from five interviewees:

Interviewee-1	Interviewee-2	Interviewee-3	Interviewee-4	On Average
5	5	4	5	4.75

Question 2:

Please estimate the proportion of data storage types (e.g. aircraft model, assembly line model, NC programme) in assembly line detail design phase (by percentage):

	Interviewee-1	Interviewee-2	Interviewee-3	Interviewee-4
On Platform(e.g. PTC Windchill)	25%	60%	20%	10%
Local personal workstation	65%	40%	40%	10%
Hardcopy	10%	-	30%	80%
Others(please point out)	-	-	-	-

Question 3:

Please choose the data/document transfer methods between design team members of SAMC and suppliers. (Please tick as appropriate, leave as blank if application is not available) (The sums of positive answers are listed)

	Interviewee-1	Interviewee-2	Interviewee-3	Interviewee-4
Via Platform(e.g. PTC windchill)			√	
E-mail	√		√	√
Hardcopy	√		√	√
FTP	√		√	√

Movable memory device	√			√
Others(please point out)		√ Dataroom.system		

Question 4:

To what extent do you agree that the automatic version control of data by work platform could greatly reduce labour hour and error rate?

5=Very much, 3=Somewhat, 1=Very little, please remark with number (1,2,3,4,5)

Interviewee-1	Interviewee-2	Interviewee-3	Interviewee-4	On Average
5	3	5	5	4.5

Question 5:

To what extent can you actually rely on established procedures and usual practice to fulfil your job in assembly line design? (5=Very much, 3=Somewhat, 1=Very little, please remark with number 1,2,3,4,5)

Interviewee-1	Interviewee-2	Interviewee-3	Interviewee-4	On Average
4	3	4	5	4

Question 6:

To what extent do you agree that, the design loop process of an assembly line detail design phase could also regard as a type of EC (engineering change) which triggered from aircraft designer? (5=Very much, 3=Somewhat, 1=Very little, please remark with number 1,2,3,4,5)

Interviewee-1	Interviewee-2	Interviewee-3	Interviewee-4	On Average
3	5	4	4	4

Question 7:

What function do you expect provided by the PDM (Product Data Management) system in the assembly line design?(Please tick as appropriate, leave as blank if no)

	Interviewee-1	Interviewee-2	Interviewee-3	Interviewee-4
Work folders for all teams	√	√	√	
Single data source	√	√	√	√
Data/Document version control	√	√	√	√
Online data transfer	√	√	√	
EMOB to MBOM conversion			√	
Visualisation of product model			√	√
Project management via workflow pre-definition & control	√	√	√	√
Others(please point out)				planning

Question 8:

Which functions do you think the mock-up on Teamcenter 8.1(in the attached PPT) covered your requirements? Please give additional comment if you want?

Functions	Interviewee-1	Interviewee-2	Interviewee-3	Interviewee-4
Functions in mock-up	√	√	√	√ **(2)**
Work folders for all teams	√	√	√	√
Single data source	√	√	√	√
Data/Document version control	√	√	√	√ **(3)**
Online data transfer	√	√	√	**X(4)**
EMOB to MBOM conversion		√	√	
Visualisation of product	(1)	√	√	√

model				
Project management via workflow pre-definition & control	√	√	√	X(5)
Other requirements(please point out)	-	-	-	-

Footnote:

(1) Comment: Not necessary for engineers but maybe useful for managers. The similar function could be provided by CATIA.
(2) Comment: Good gravity
(3) Comment: need to improve the detail information for every version. Better identification.
(4) Comment: Need to improve with electronic deliver transfer data, no hand copy.
(5) comment: Need to improve the communication with the product design team.

Question 9:

Which extra function do you expect provided by IT environment to speed up the concurrent work process and collaboration in assembly line design?

Interviewee-1	Suggest connecting the design platform of aircraft and assembly line and automatic data transfer. Also the version connection between tooling data and aircraft data need to be built.
Interviewee-2	1. remote conference and data sharing tool 2. database include tooling and tools

	3. task tracking system 4. training
Interviewee-3	Suggest unifying the design platform of aircraft and assembly line.
Interviewee-4	Suggest improving the changes in the information.

In the AS-IS part, the assertion that detail design work of AL in this phase could be regarded as comprised by data/document work, scored high agreement (5-=very much, average mark is 4.75). Regarding the data storage types, partly because the interviewees were required to estimate the proportion, 4 sets of feedback gave dissimilar answers, but 3 of them indicated that no more than 25% of design data was stored on the PDM system. Also regarding this question, only one feedback pointed out that the data transfer did not relying on work platform, E-mail, FTP, hardcopy and movable memory device, but by a file sharing system (Data room). Regarding the certainty of the work process, feedback indicated that people tended to agree that the design process could follow existing regular practice but uncertainty would still be encountered. Meanwhile, there was a moderate acceptance that the design process of AL in this phase could be regarded as an EC (engineering change) activity triggered by the A/C designer.

In the part of TO-BE, nearly all agreed that an automatic version control system could introduce convenience and reduce error rate (5-=very much, average mark is 4.5). Regarding the expectation of the work platform, half indicated that converting EBOM to MBOM was unnecessary. Two people argued that the product visualisation was not useful. An interviewee from the supplier regards the online data transfer as unwanted.

The last part was to obtain interviewees' judgement on the mock-up. After viewing the illustrated pages of Appendix E, the interviewees gave high agreement that the demonstrated functions could cover their requirements. They also suggested that the future work platform should improve the system integration between A/C and AL design organisations to facilitate change management, pave the way for dataflow and workflow, and introduce a knowledge management module and remote collaborative design tool.

In summary, the feedback indicated that the basic elements of AS-IS and proposed solution were confirmed by the key people who were working in the SAMC AL projects. The main limitation was due to the geographical distance which resulted in the detail of the mock-up not being fully demonstrated to interviewees.

6.3 Overall project review

The concurrent assembly line design, especially in the Detail Design stage, were mainly related to improving detail drawings, specs and plans, as found in literature review and the AS-IS chapters. So dataflow in the parallel design process could be regarded as an indicator of the effect of CE implementation.

Following the case study process (Fleischer and Liker, 1997), an investigation was carried out based on the author's work experience, interviews with team members and documents available. In this process, the critical issue was to avoid bias and prejudice. So part of the questionnaire was used for validating the conclusion of AS-IS.

In the AS-IS report, the context of SAMC AL project fitted well with the research framework provided by Fleischer and Liker (1997). In the detail study of workflow and dataflow, the author documented the specific work process content in the aircraft assembly line design. By comparison with publications and benchmarking, the final conclusion was that although SAMC could adopt the CE principle by employing team work and parallel design process of A/C and AL, the lack of an integrated IT environment would result in the team members having to spend extra time and labour on information exchange and management. This was a common issue for distributed product development and precedents could be found from Boeing and Airbus.

To design the proposed solution based on current available technology, PLM, or at last the core data management module, PDM should be introduced. For implementation, SAMC would have to accept the heterogeneous environment and use ICT as the bridge for different platforms for data flow and work flow. To implement the technology smoothly, the workflow pattern needed to be defined for the common design platform. The author analysed and standardised the peer-to peer collaborative design activates, and connect them with the corresponding data/documents.

From the AL design activities, a common model was built and the data-centric tasks were categorised. The theoretical model was simulated on software to confirm the feasibility in the real world. Teamcenter 8 was chose as the testing platform. By using assumed AL design data, the basic function of the data flow model was validated. However, the result also showed the gap between general commercial PLM software WFM and the specific workflow/dataflow requirement of AL design. In the mock-up, only one mainstream PLM software was tested without the exploration of multiple platforms. If multiple platforms were to be tested, it would be important to investigate and standardise the work convention detail to ensure high compatibility.

The last work was to gather expert's opinion and analyse the feedback. The sample size of the questionnaire was lower than initially expected, but still sufficient to confirm the proposal. The interviewees from the SAMC AL project commented on the AS-IS and mock-up from their work experience, understanding of data management/exchanges and PDM. They supported the results of this research and indicated the urgency of deploying the integrated work platform for AL development.

The overall research route could be found in Figure 6-1.

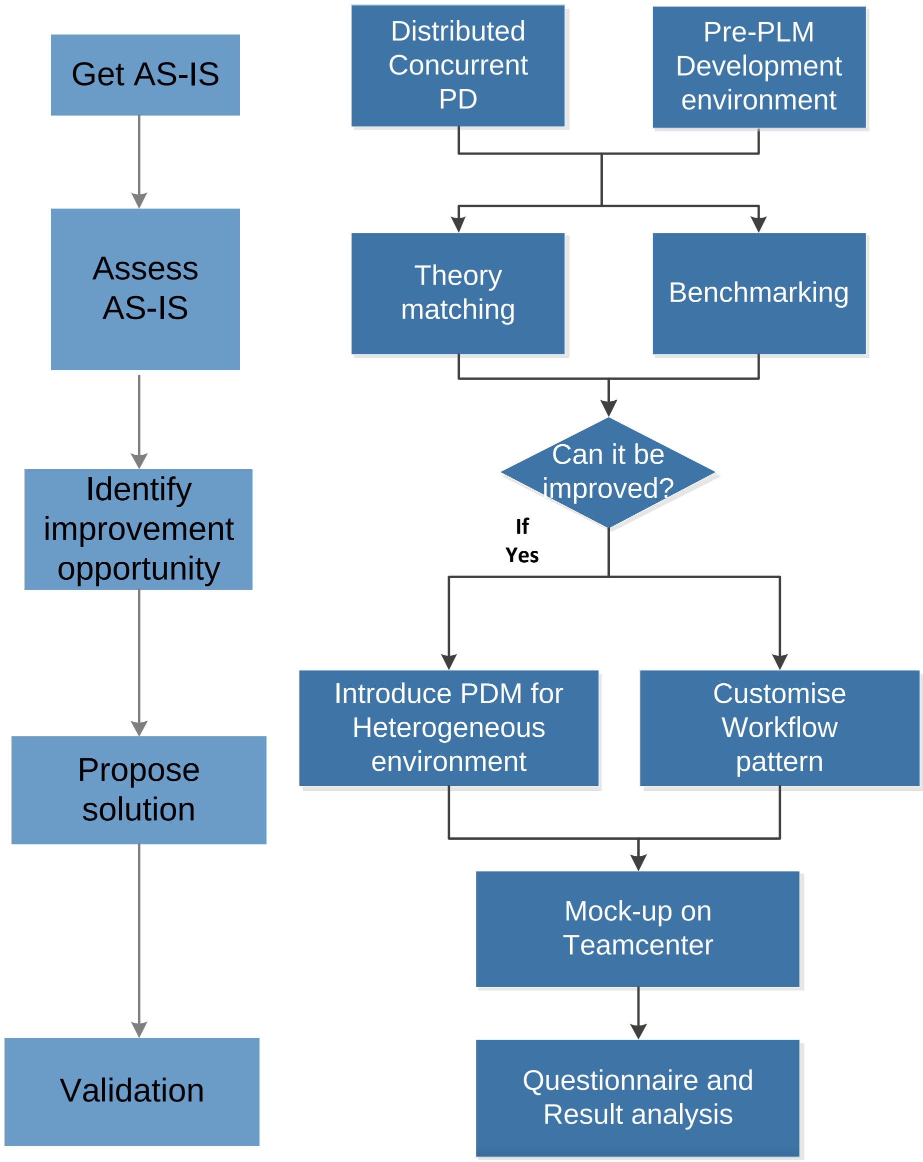


Figure 6-1 The research path

6.4 Consideration of execution

6.4.1 Avoiding pitfalls

As mentioned in Section 6.1, Merminod and Blanco (2008) reported that in the case of a company deploying a collaborative platform (Teamcenter), people were found to be still largely relying on other tools, especially E-mail, for data sharing and negotiation in the product design process. The reason WFM was not working as expected could be due to the rigid workflow design while the uncertainty in collaborative PD demanded flexibility with workflow. Hence, the design of the work platform should carefully consider the work practice and the requirement of the informal activity, for example, draft document sharing and commenting. Otherwise, the application of the WFM module would ultimately be unsuccessful.

In the proposed solution, the overall work process was broken down into tasks as basic segments, and any authorised member could create and release workflow based on data/document centric tasks. This design was different from previous WFM in the SAMC PDM systems; in which the workflow followed a rigid pre-defined template and only a few people can modify it. This autonomous-like paradigm enabled team members with more flexibility to adapt to the uncertainness of PD. People could share and comment on drafts and receives notification once the relevant information is updated. The formal approval process of design could be customised conveniently. A holistic view of workflow and notification mechanism could give the project manager and other users a clear idea of the work condition. While the peer-to-peer interoperability was enhanced, the monitoring of information flow between SAMC and supplier teams by the project manager still remains.

6.4.2 Workflow models need more detail for implementation

The proposed workflow model and tested mock-up provided a new pattern of WFM compared to previous works. The lack of detailed case studies had been mentioned in Chapter 2, and some studies on workflow in assembly line/tooling design processes were over conceptual, which resulted in application difficulties for customising the workflow template. For example, Li et al. (2008) provided a closed loop tooling design process (see Figure 2-14) based PDM. However, it was drawn in a single discipline view, without the consideration of interaction with upstream and downstream disciplines. Not only product data, but also other information e.g. assembly plan, cost estimation and fabrication schedule needed to be incorporated in real product development, and documents were still indispensable as vehicles of such information.

The diagram of concurrent assembly line process by Rekiek and Delchambre (2006, p.122) was a good fit for the real design process, and details about workflow and dataflow were also discussed there. However, the supporting tool/environment of concurrent design was missing. In the case study of Airbus (2013), iDMU was the tool for connecting the design of the A/C, manufacturing process and resource plan in the virtual environment. However, the detailed work mechanism among disciplines was not reported.

From the studies above, the work of extracting detailed workflow and dataflow model in assembly line design contributes a valuable reference for enterprises wanting to convert the workflow practice from pre-PLM to PLM platform. This provides a convenient starting point for enterprise to detail their particular case analysis and customisation.

This research focuses on the detail design phase, but an assembly line project will finally enters the production phase and connects with more of physical activities, and the collaborative platform will cross the PLM and ERP systems. The information transfer between the two systems will constitute another challenge, and the enterprises need to consider the data unity and integrity issues before implementation. None should be an isolated island, as Stark (2011) says.

7 Conclusion

7.1 Achieving Objectives

Through the investigation of concurrent engineering practice in the SAMC assembly project, the work context: people, organisation, technology, strategy were clarified. The work process in assembly design was mapped. The global workflow and dataflow model was documented as flowcharts. By comparison with published literature and bench marking, the simultaneous work on three levels was identified. The main weakness of the current situation was the lack of an integrated work environment to support data management/exchange and workflow management between the three collaborative entities: SADRI, SAMC and supplier. Hence, the effect of concurrent engineering was not realised.

In the literature review, the state-of-art of supporting environment for distributed concurrent product development like PDM/PLM was studied as a possible approach. Considering the SAMC particular infrastructure and work conventions, a set of data management/exchange and cross-discipline/organisation automatic workflow model based on heterogeneous PLM system were proposed. The workflow and dataflow were connected by using the activity-oriented methodology to decompose the design loop to data/document-centric operations. Three types of operations are categorised: Do, Acknowledge and Evaluate; and detail operation to match the AL work practice were discussed.

To test the feasibility, the proposed solution was mocked-up in the Siemens Teamcenter 8.1 software, one of the mainstream PLM systems. The result demonstrated that the core function requirements such as data management and exchanging could be fully satisfied, while the automatic workflow management still needed to be further developed to better match the custom and practice.

Finally, the main work result of AS-IS and proposed solution on Teamcenter were documented in a brief questionnaire, and sent to key people working on the SAMC AL project. Their feedback showed high level of agreement on the description of AS-IS and confirmed that the proposed solution could facilitate the data management/exchange and collaborative design activities in the AL project. They also expressed the expectation of future work platforms, e.g. enhance systems integration, design change management, knowledge management, and so on.

To summarise this research, the main obstacles to CE success in the on-going SAMC AL projects were identified, and based on state-of-the-art, a set of data flow/workflow solution model supported by PLM system was proposed. The feasibility was successfully tested by mock-up with mainstream software. Finally, the proposed solution was validated by questionnaire. However, the main limitation of this research was the lack of implementation experience in the AL project to be certain of applicability and discover more improvement opportunities. This research also suggests that, for the diversity industry practice, the flexibility of the workflow management function of PLM software still needs to be improved to better fit customers' expectations.

7.2 Further research suggestion

As in Section 6.1 and pointed out by other researchers (Merminod and Blanco, 2008; Vila et al., 2002), while PDM supported data management and exchange have been maturing, the cross-discipline/concurrent workflow on collaborative platforms still have room for improvement. The detail design of workflow management in PDM/PLM tools should gather more experience form a variety of product development cases to improve the interoperability, concurrency and flexibility.

Systems integration is also a noticeable problem for enterprise transforming from pre-PLM to deploying PLM systems. Essentially, workflow and dataflow among disciplines/departments in the whole product lifecycle should not have any barriers. When a company introduces new CAx/PDM/MES/ERP et al. systems and starts a large scale project with global collaborative partners, fusing all systems together is a big challenge. More cases should be explored to find the advantages and weaknesses of collaborative work platform.

REFERENCES

[1] Addo-Tenkorang, R. (2011), "Concurrent Engineering (CE): A Review Literature Report", *Proceedings of the World Congress on Engineering and Computer Science,* Vol. 2, pp. 19.

[2] Aguilar-Savén, R. S. (2004), "Business process modelling: Review and framework", *International Journal of Production Economics,* vol. 90, no. 2, pp. 129-149.

[3] ANSI/EIA (2011), *ANSI/EIA 649: national consensus standard for configuration management*. American National Standards Institute.

[4] Bartholomew, D., “PLM: Boeing's Dream, Airbus' Nightmare”, in *Baseline (February 5, 2007).*

[5] Chen, Y. and Hsiao, Y. (1997),"A collaborative data management framework for concurrent product and process development"*, International Journal of Computer Integrated* Manufacturing, vol. 10, no. 6, pp. 446-469.

[6] Chen, Y. and Liang, M. (2000), *"Design and implementation of a collaborative engineering information system for allied concurrent engineering"*, *International Journal of Computer Integrated Manufacturing*, vol. 13, no. 1, pp. 11-30.

[7] Chryssolouris, G., Mavrikios, D., Papakostas, N., Mourtzis, D., Michalos, G. and Georgoulias, K. (2009), "Digital manufacturing: history, perspectives, and outlook", *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, vol. 223, no. 5, pp. 451-462.*

[8] Dekkers, R., Chang, C. M. and Kreutzfeldt, J.(2013) "The interface between “product design and engineering” and manufacturing: A review of the literature and empirical evidence", *International Journal of Production Economics,* Vol.144, no.1, p.316-333.

[9] Delchambre, A. (1996), *CAD Method for Industrial Assembly: Concurrent Design of Products, Equipment, and Control Systems (1st ed)*, John Wiley & Sons, Inc., West Sussex.

[10] Earl, C., Johnson, J. and Eckert, C. (2005), "Complexity", in: *Design process improvement*, Springer-Verlag, London, pp. 174-197.

[11] Eckert, C., Maier, A. and McMahon, C. (2005), "Communication in design", in: *Design process improvement*, Springer-Verlag, London, pp. 232-261.

[12] Gunpinar, E. and Han, S. (2008), "Interfacing heterogeneous PDM systems using the PLM Services", *Advanced Engineering Informatics*, vol. 22, no. 3, pp. 307-316.

[13] Georgakopoulos, D., Hornick, M. and Sheth, A. (1995), "An overview of workflow management: From process modeling to workflow automation infrastructure", *Distributed and parallel Databases*, vol. 3, no. 2, pp. 119-153.

[14] Fan Yuqing (2001), *Technology of Modern Aircraft Manufacturing,* Beihang University Press, Beijing. 范玉青 (2001), 现代飞机制造技术, 北京航空天大学出版社, 北京.

[15] Figay, N. and Ghodous, P. (2008), "Collaborative Product Development: EADS Pilot Based on ATHENA", in: *Enterprise Interoperability III*, Springer, London, pp. 423-435.

[16] Fleischer, M. and Liker, J. K. (1997), Concurrent engineering effectiveness: integrating product development across organizations, Hanser Gardner Publications, Cincinnati, OH, 1997.

[17] Forsberg, M. and Johansson, A. (2008) "A Standardised Approach to Technical Manufacturing Information"(Master's thesis), Luleå University of Technology, Luleå.

[18] Huet, G., Fortin, C., Mcsorley, G. and Toche, B. (2009), "Information structures and processes to support data exchange between product development and resource planning systems", *Proceedings of the IESM'09 International Conference on Industrial Engineering and Systems Management.*

[19] International, M. E. S. A.(2004) "Collaborative manufacturing explained. MESA International—White Paper", *available at:https://services.mesa.org/resourcelibrary/showresource/9fc12f9d-c082-4f6a-a1dd-65304a7e34bc* (Accessed 26th Nov, 2013).

[20] Jarratt, T., Clarkson, J. and Eckert, C. (2005), "Engineering change", in *Design process improvement,* Springer-Verlag, London, pp. 262-285.

[21] Jørgensen, N. (2006), "The Boeing 777: Development Life Cycle Follows Artifact", *World Conference on Integrated Design and Process Technology (IDPT)*,June 25-30, 2006, San Diego, California,

[22] Jianyu, W., Ke, L. and Saiqun, L. (2012), "The Research of PDM System for the Collaborative Design of Functional Structure", in: *Advances in Electric and Electronics*, Springer, pp. 107-114.

[23] Kolfschoten, G. L. (2007), "Theoretical foundations for collaboration engineering", *Delft University of Technology,* The Netherlands.

[24] Kotha, S. and Srikanth, K. (2013), "Managing a global partnership model: lessons from the Boeing 787 ‘Dreamliner’ program", *Global Strategy Journal,* vol. 3, no. 1, pp. 41-66.

[25] Koufteros, X., Vonderembse, M. and Doll, W. (2001), "Concurrent engineering and its consequences", *Journal of Operations Management,* vol. 19, no. 1, pp. 97-115.

[26] Kovacs, Z. (1999), The Integration of Product Data with Workflow Management Systems through a Common Data Model, PhD diss., Faculty of Computer Studies and Mathematics, University of the West of England, Bristol.

[27] Lee, C., Leem, C. S. and Hwang, I. (2011), "PDM and ERP integration methodology using digital manufacturing to support global manufacturing", *The International Journal of Advanced Manufacturing Technology*, vol. 53, no. 1-4, pp. 399-409.

[28] Li, W. D. and Qiu, Z. M. (2006), "State-of-the-art technologies and methodologies for collaborative product development systems", *International Journal of Production Research,* vol. 44, no. 13, pp. 2525-2559.

[29] Li, Y., Pan, Z., Yan, R. and Liao, W. (2008), "A PDM-based framework for collaborative aircraft tooling design", *International Journal of Production Research,* vol. 46, no. 9, pp. 2413-2431.

[30] Mas, F., Ríos, J., Menéndez, J. L., Hernández, J. C. and Vizán, A. (2008), "Concurrent conceptual design of aero-structure assembly lines", *Proceedings of the 14th Intl. Conf. on Concurrent Enterprising (ICE), Lisbon, Portugal,* pp. 783.

[31] Mas, F., Menéndez, J., Oliva, M. and Ríos, J. (2013), "Collaborative Engineering: an Airbus case study", *5th Manufacturing Engineering Society International Conference*, June 26th-28th, 2013, Zaragoza.

[32] Mayer, R. J., Crump, J. W., Fernandes, R., Keen, A. and Painter, M. K. (1995), *Information integration for concurrent engineering (IICE) compendium of methods report*, Knowledge based system Inc., TX.

[33] McClatchey, R., Baker, N., Harris, W., Le Goff, J., Kovacs, Z., Estrella, F., Bazan, A. and Le Flour, T. (1997), "Version management in a distributed workflow application", Database and Expert Systems Applications, 1997. Proceedings. Eighth International Workshop on Workflow Management in

Scientific and Engineering Applications, 1-2 Sept.1997, Toulouse, France, pp.10-15.

[34] McClatchey, R., Kovacs, Z., Estrella, F., Le Goff, J., Chevenier, G., Baker, N., Lieunard, S., Murray, S., Le Flour, T. and Bazan, A. (1998), "The integration of product data and workflow management systems in a large scale engineering database application", *Database Engineering and Applications Symposium, 1998. Proceedings. IDEAS'98. International,* IEEE, pp. 296.

[35] McClellan, M. (2002), *Collaborative manufacturing: using real-time information to support the supply chain,* CRC Press, CRC Press, Boca Raton, Florida.

[36] Meerkamm, H and Koch, M (2005), *"Communication in design*", in Design process improvement, Springer-Verlag, pp. 306-323.

[37] Merminod, V. and Blanco, E. (2008), "PLM opportunities and weaknesses to support collaborative engineering", In:*International Product Development Management Conference,* Hamburg.

[38] Mesihovic, S., Malmqvist, J. and Pikosz, P. (2004), "Product data management system-based support for engineering project management", *Journal of Engineering Design*, vol. 15, no. 4, pp. 389-403.

[39] Mills, A. (1998), *Collaborative engineering and the Internet: linking product development partners via the web,* SME, Dearborn.

[40] Ming, X., Yan, J., Wang, X., Li, S., Lu, W., Peng, Q. and Ma, Y. (2008), "*Collaborative process planning and manufacturing in product lifecycle management*", *Computers in Industry,* vol. 59, no. 2, pp. 154-166.

[41] Munk, C. (2009), "Aircraft manufacturing and assembly", in: *Springer Handbook of Automation*, Springer Berlin Heidelberg, pp. 893-910.

[42] O'Donovan, B., John Clarkson, M. and Browning, T. R. (2005), "Design planning and modelling", in:*Design process improvement*, Springer-Verlag, pp. 60-87.

[43] Pardessus, T. (2004), "Concurrent engineering development and practices for aircraft design at Airbus", Proceedings of the 24th ICAS Conf., Yokohama, Japan.

[44] Pennell, J. P. and Winner, R. I. (1989), "Concurrent engineering: practices and prospects", *Global Telecommunications Conference, 1989,*

and Exhibition. Communications Technology for the 1990s and Beyond. GLOBECOM'89., IEEE, pp. 647.

[45] Patil, V. and Chaudhari, A. (2002), "Cross Organizational Workflow Management Systems", *Product Data Technology Europe,* vol. 2002, pp. 7-9.

[46] Prasad, B., Wang, F. and Deng, J. (1998), "A concurrent workflow management process for integrated product development", *Journal of Engineering Design,* vol. 9, no. 2, pp. 121-135.

[47] Pullan, T. T., Bhasi, M. and Madhu, G. (2010), "Application of concurrent engineering in manufacturing industry", *International Journal of Computer Integrated Manufacturing,* vol. 23, no. 5, pp. 425-440.

[48] Smparounis, K., Alexopoulos, K., Xanthakis, V., Pappas, M., Mavrikios, D. and Chryssolouris, G. (2009), "A Web-based platform for Collaborative Product Design and Evaluation", *15th International Conference on Concurrent Enterprising (ICE), 22-24 June 2009, Leiden,The Netherlands*.

[49] Qiu, Z. and Wong, Y. (2007), "Dynamic workflow change in PDM systems", *Computers in Industry,* vol. 58, no. 5, pp. 453-463.

[50] Rachuri, S., Subrahmanian, E., Bouras, A., Fenves, S. J., Foufou, S. and Sriram, R. D. (2008), "Information sharing and exchange in the context of product lifecycle management: Role of standards", *Computer-Aided Design,* vol. 40, no. 7, pp. 789-800.

[51] Ranky, Paul G (1994). *Concurrent/simultaneous engineering: (methods, tools & case studies)*. CIMware, Guildford.

[52] Rashid, M. A., Riaz, Z., Turan, E., Haskilic, V., Sunje, A. and Khan, N. (2012), "Smart factory: E-business perspective of enhanced ERP in aircraft manufacturing industry", *Technology Management for Emerging Technologies (PICMET), 2012 Proceedings of PICMET'12:* IEEE, pp. 3262

[53] Rekiek, B. and Delchambre, A. (2006), "*Assembly line design: the balancing of mixed-model hybrid assembly lines with genetic algorithms. Springer series in advanced manufacturing*",Springer-Verlag, London.

[54] Sorli, M. and Stokic, D. (2009), *Innovation in Product/Process Development: Gaining Pace in New Product Development,* Springer-Verlag, London.

[55] Rouibah, K. (2003), "*Managing concurrent engineering across company borders: a case study*", *System Sciences, 2003. Proceedings of the 36th Annual Hawaii International Conference on,* IEEE, pp.1-11.

[56] Rouibah, K., Rouibah, S. and Van Der Aalst, W. (2007), "*Combining workflow and PDM based on the workflow management coalition and STEP standards: the case of axalant*", *International Journal of Computer Integrated Manufacturing,* vol. 20, no. 8, pp. 811-827.

[57] Rupp, T. M. (2004), "*Towards Collaborative Engineering in the Aerospace Industry*", *ICE2004. Proceedings of the 10th International Conference on Concurrent Enterprising. Sevilla,* pp. 195-202.

[58] Savant, P. and Al-Ashaab, A. (2009), *Developing a product data structure to implement PLM in a company,* Master thesis, Cranfield University, Cranfield.

[59] Shehab, E., Fowler, C., Rodriguez Gil, A., Abdalla, H., Darwish, M., Abdulhafed, H., Ahmed, A., Ahouie, H., Alechnovic, A., Paumes, C., Tacchini, E., Urbane, I. and Richardson, M. (2013), "*Enhancement of product information collaboration and access in the aerospace industry*", *International Journal of Production Research,* vol. 51, pp. 1-16.

[60] Shen, W., Hao, Q. and Li, W. (2008), "*Computer supported collaborative design: Retrospective and perspective*", Computers in Industry, vol. 59, no. 9, pp. 855-862.

[61] Shen, W., Hao, Q. and Li, W. (2013), "*Survey on Distributed Collaborative Engineering and Applications*", in *Cloud Manufacturing*, Springer, pp. 217-242.

[62] Spitz, W., Golaszewski, R., Berardino, F. and Johnson, J. (2001), *Development cycle time simulation for civil aircraft*, -NASA/CR-2001-210658, National Aeronautics and Space Administration, Langley Research Center，Hampton, Virginia，USA.

[63] Stark, J. (2011), *Product lifecycle management (2nd ed),* Springer-Verlag, London.

[64] Swink, M. L., Sandvig, J. C. and Mabert, V. A. (1996), "Customizing concurrent engineering processes: five case studies", *Journal of Product Innovation Management,* vol. 13, no. 3, pp. 229-244

[65] Vajna, S. (2005), "Workflow for design", in: *Designprocess improvement*, Springer-Verlag, London, pp. 366-385.

[66] Vila, C., Romero, F. and Galmés, V.(2002), "Workflow and Product Data Management in Heterogeneous CAx Concurrent Engineering Environments". The 8th International Conference on Concurrent Enterprising. Rome, Italy, 17-19 June 2002

[67] Vila, C., Estruch, A., Siller, H. R., Abellán, J. V. and Romero, F. (2007), "Workflow methodology for collaborative design and manufacturing", in *Cooperative Design, Visualization, and Engineering*, Springer, pp. 42-49.

[68] Watts, F.B.(2008), *Engineering Documentation Control Handbook - Configuration Management in Industry (3rd Ed)*, William Andrew Publishing, New York.

[69] Willaert, S. S., De Graaf, R. and Minderhoud, S. (1998), *"Collaborative engineering: a case study of concurrent engineering in a wider context", Journal of Engineering and Technology Management*, vol. 15, no. 1, pp. 87-109.

[70] Yang, J., Han, S., Grau, M. and Mun, D. (2008), "OpenPDM-based product data exchange among heterogeneous PDM systems in a distributed environment", *The International Journal of Advanced Manufacturing Technology,* vol. 40, no. 9-10, pp. 1033-1043

[71] Dassault Systèmes http://www.3ds.com/solutions/(Accessed 26th Nov,2013)

[72] PTC http://www.ptc.com/appserver/wcms/standards/textsub.jsp?&im_dbkey=132818&icg_dbkey=21. (Accessed 26th Nov,2013)

[73] Siemens http://www.plm.automation.siemens.com/en_gb/products/teamcenter/(Accessed 26th Nov,2013)

APPENDICES

Appendix A Data generated in AL design

No.	Data Type	Data format	Store platform	Transfer route	Note
1.	Aircraft Product Model	CATpart /product (MBD)	PTC Windchill PDMLink server	1.Be shared in PTC Windchill server 2.Movable memory disk 3.FTP	1.Normally 2D drawings are no more using.
2	Engineering Bill of Material (EBOM)	1.Structured Data 2.xls(MS Excel)	PTC Windchill PDMLink server	1.Be shared in PTC Windchill server 2.Movable memory disk 3.FTP	The structured EBOM could be output as .xls table.
3	Aircraft Technical Specification	PDF	PTC Windchill PDMLink server	1.Be shared in PTC Windchill server 2.Movable memory disk 3.FTP	
4	Engineering Data Drops Status	.doc(MS Word)	Local PC	1.Be shared in PTC Windchill server 2.Movable memory disk 3.FTP	
5	Project scheduling(SAMC)	.mpp(MS Project)	Local PC	1.E-mail 2.Movable memory disk 3.FTP	
6	Project Weekly report(SAMC)	.doc(MS Word)	Local PC	1.E-mail 2. Movable memory disk 3.FTP	
7	Assembly plan(SAMC)	(1) .doc(MS Word) (2) .xls(MS Excel)	Local PC	1.E-mail 2. Movable memory disk 3.FTP	It is a comprehensive document package includes three types data for different purposes: 1.Text for describe the operation 2.Tables are used to describe the operation time and items sequence and consumption
8	Manufacturing Bill of Material (MBOM)(SAMC)	(1)Structured data in platform (2) XLS(MS Excel)	(1)PTC Windchill PDMLink server (2)Local PC	Be shares in PTCWindchill server E-mail Movable memory disk FTP	The MBOM can be re-structured from EBOM and stored in the PTC Winchill platform, also can be outputted as XLS document.
9	Assembly line layout(SAMC)	1.CATIA 2.AutoCAD	Local PC	1.E-mail 2.Movable memory disk 3.FTP	Both drawling formats are acceptable.
10	Assembly tooling definition (SAMC)	.doc(MS Word)	Local PC	1.E-mail 2.Movable memory disk 3.FTP	
11	Assembly equipment requirement(SAMC)	.doc (MS Word)	Local PC	1.E-mail 2.Movable memory disk 3.FTP	
12	Manufacturability feedback(SAMC)	.doc(MS Word)	Local PC	1.E-mail 2.Movable memory disk 3.FTP	
13	Equipment Specification(SAMC)	.doc(MS Word)	Local PC	1.E-mail 2.Movable memory disk 3.FTP	
14	Quality assurance plan/QFD	.doc(MS Word)	Local PC	1.E-mail 2.Movable	

				memory disk	
15	Assembly line Layout(SAMC)	CATIA AutoCAD	Local PC	1.E-mail 2.Movable memory disk 3.FTP	
16	Production Capacity Assessment(SAMC)	.xls(MS Excel)	Local PC	1.E-mail 2.Movable memory disk 3.FTP	
17	Assembly plan(supplier)	(1).doc(MS Word) (2).xls(MS Excel)	Local PC	1.E-mail 2.Movable memory disk 3.FTP	This data package is comprised as 8.
18	Assembly Line Operation Simulation (supplier)	CATIA/DELMIA Output to Video	Local PC	1.E-mail 2.Movable memory disk 3.FTP	
19	Tooling design Model and drawling	CATIA	Local PC	1.E-mail 2.Movable memory disk 3.FTP	
20	Assembly line Tooling specification(supplier)	. ppt(MS PowerPoint)	Local PC	1.E-mail 2.Movable memory disk 3.FTP	
21	Healthy, Safety, and Ergonomic report(supplier)	.ppt(MS PowerPoint)	Local PC	1.E-mail 2.Movable memory disk 3.FTP	
22	Assembly line Layout(supplier)	CATIA	Local PC	1.E-mail 2.Movable memory disk 3.FTP	
23	Assembly line Construction drawing(supplier)	CATIA	Local PC	1.E-mail 2.Movable memory disk 3.FTP	It is mainly used to define the construction requirement
24	Production Capacity Assessment(supplier)	.xls(MS Excel)	Local PC	1.E-mail 2.Movable memory disk 3.FTP	
25	Manufacturability feedback(supplier)	.doc(MS Word)	Local PC	1.E-mail 2.Movable memory disk 3.FTP	
26	Equipment Specification(supplier)	.doc(MS Word)	Local PC	1.E-mail 2.Movable memory disk 3.FTP	Equipment: e.g. Robot, NC machine, AGV, Crane.
27	Equipment Running simulation	.CATprocess (Dassault CATIA/DELMIA)	Local PC	1.Movable memory disk 2.FTP	
28	NC Programme	---	Local PC	1.E-mail 2.Movable memory disk 3.FTP	
29	Assembly line project schedule(supplier)	.mpp(MS Project)	Local PC	1.E-mail 2.Movable memory disk 3.FTP	
30	Maintenance Plan(supplier)	.doc(MS Word)	Local PC	1.E-mail 2.Movable memory disk 3.FTP	
31	Assembly Line Changing report	.xls(MS Excel)	Local PC	1.E-mail 2.Movable memory disk	
32	Weekly progress report(supplier)	.ppt(MS PowerPoint)	Local PC	1.E-mail 2. Movable memory disk	

				3.FTP	

Appendix B Workflow and dataflow in SAMC assembly line detailed design phase

Appendix C Form of Task Interdependence

P=Pooled S=Sequential R=Reciprocal Roles in column are task trigger	Assembly line Project manager(SAMC)	Assembly Engineer(SAMC)	Tooling Designer(SAMC)	Equipment engineering(SAMC)	Quality engineer (SAMC)	Facility and resource planning engineer(SAMC)
Aircraft designer	S	R	S	S	S	S
Assembly line Project manager(SAMC)		R	R	R	S	R
Assembly Engineer(SAMC)			R	R	R	S
Tooling Designer(SAMC)				S	S	R
Equipment engineering(SAMC)					S	S
Quality engineer(SAMC)						S

Appendix D Cross Functional Communication Matrix

One-way, feed-forward → One-way, feedback 2-way, asynchronous ⇄ 2-way,synchronous ↔ Bland=no communication 1= low frequency 2=medium frequency 3=high frequency	Assembly line Project manager(SAMC)	Assembly Engineer(SAMC)	Tooling Designer(SAMC)	Equipment engineering(SAMC)	Quality engineer (SAMC)	Facility and resource planning engineer(SAMC)
Aircraft designer	⇄ 1	⇄ 3	→ 2	→ 2	⇄ 1	→ 1
Assembly line Project manager(SAMC)		⇄ 3	⇄ 2	⇄ 2	⇄ 1	⇄ 1
Assembly Engineer(SAMC)			⇄ 3	⇄ 2	⇄ 1	⇄ 1

Tooling Designer(SAMC)				⇄ 1	⇄	⇄ 2
Equipment engineering(SAMC)					⇄ 1	⇄ 2
Quality engineer(SAMC)						⇄ 1

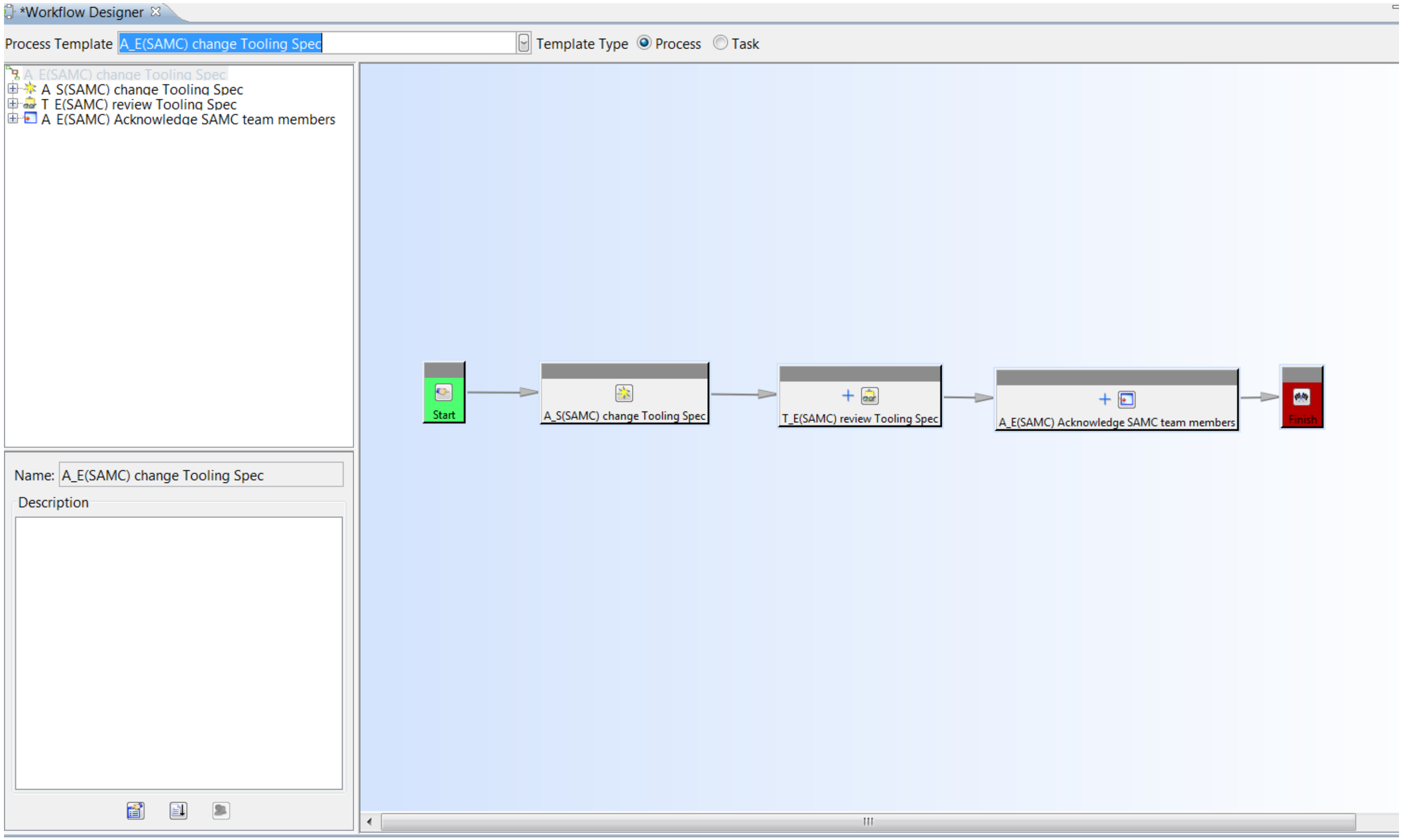
Appendix E Detail illustration of workflow in Mock-up

E.1 The roles created in Teamcenter 8.1

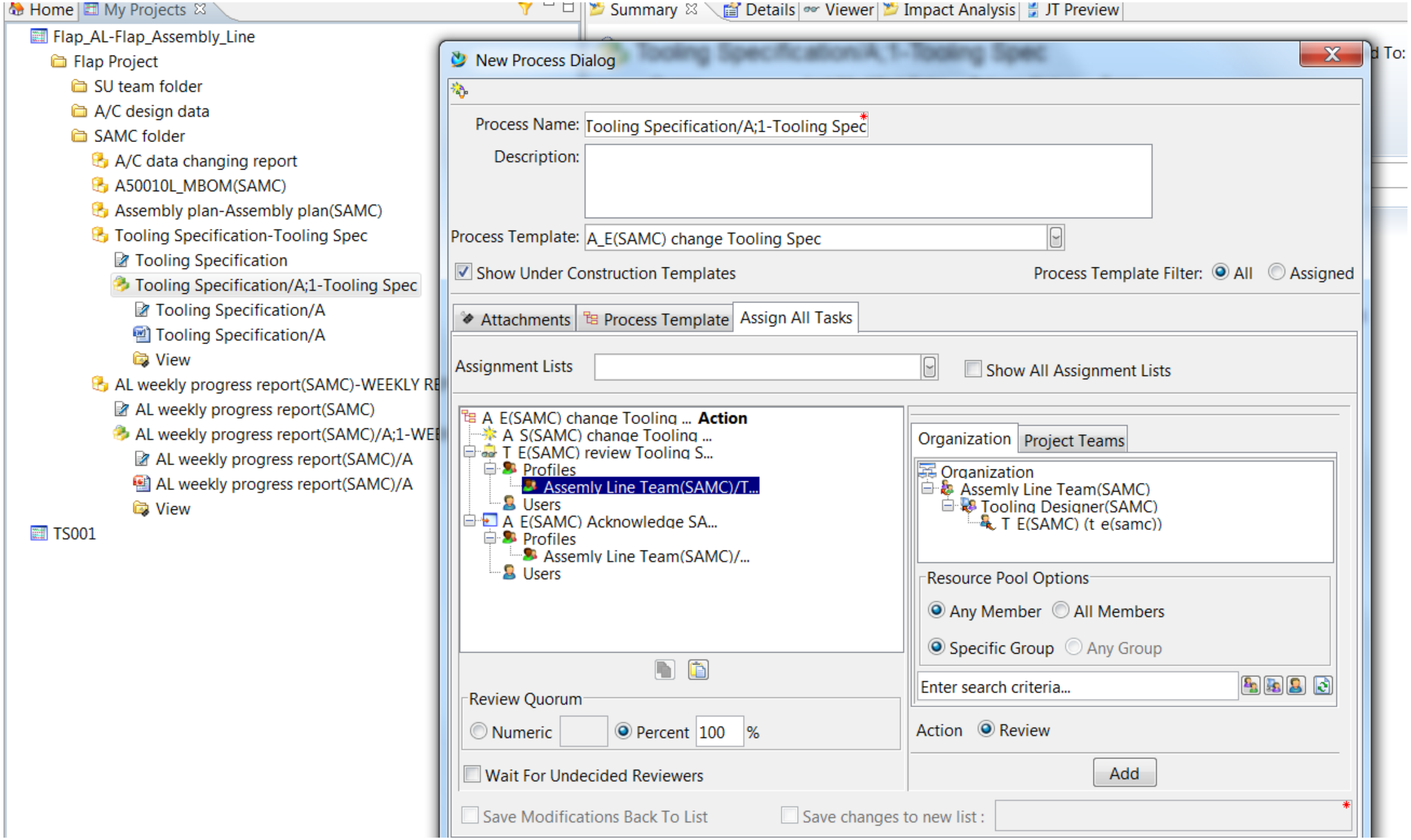
No.	Role's name in Teamcenter	Corresponding role in The Real world
1.	S_E(SAMC)	Senior Engineer of SAMC
2.	A_E(SAMC)	Assembly Engineer of SAMC
3.	P_M(SAMC)	Project manager of SAMC
4.	T_E(SAMC)	Assessment Tooling design of SAMC
5.	Q_E(SAMC)	Quality engineer of SAMC
6.	C_E(SAMC)	Cost engineer of SAMC
7.	F&R_E(SAMC)	Facility and resource planning engineer of SAMC
8.	P_M(SU)	Project manager of suppler
9.	ASSY_E(SU)	Assembly Engineer of supplier
10.	T_D(SU)	Assessment Tooling design of supplier
11.	E_E(SU)	Equipment engineer of supplier
12.	M_E(SU)	Metrology engineer of supplier

E.2 The workflow of changing the tooling spec document of SAMC in Teamcenter 8.1

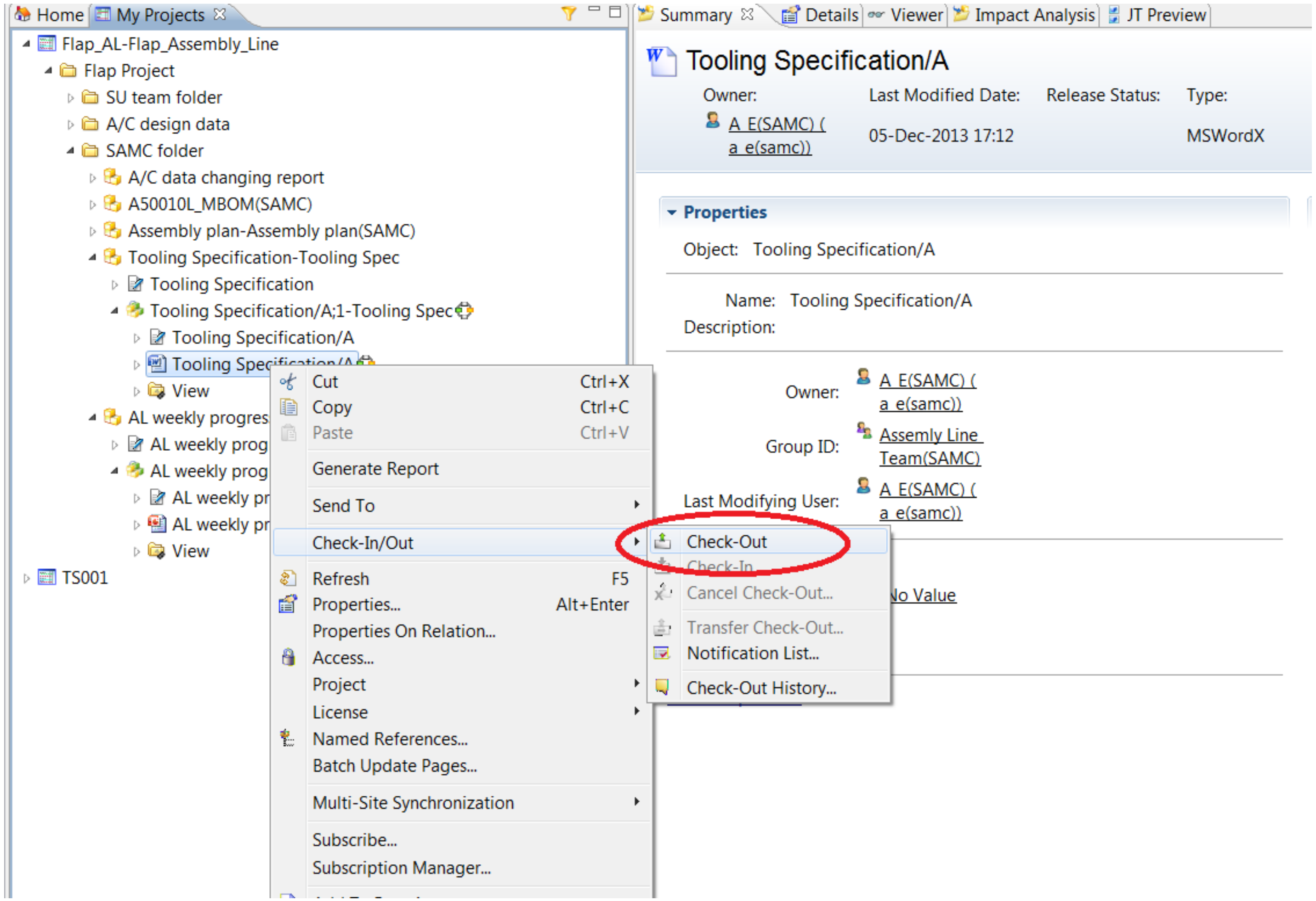
1. Create the workflow template of Changing tooling spec in SAMC team



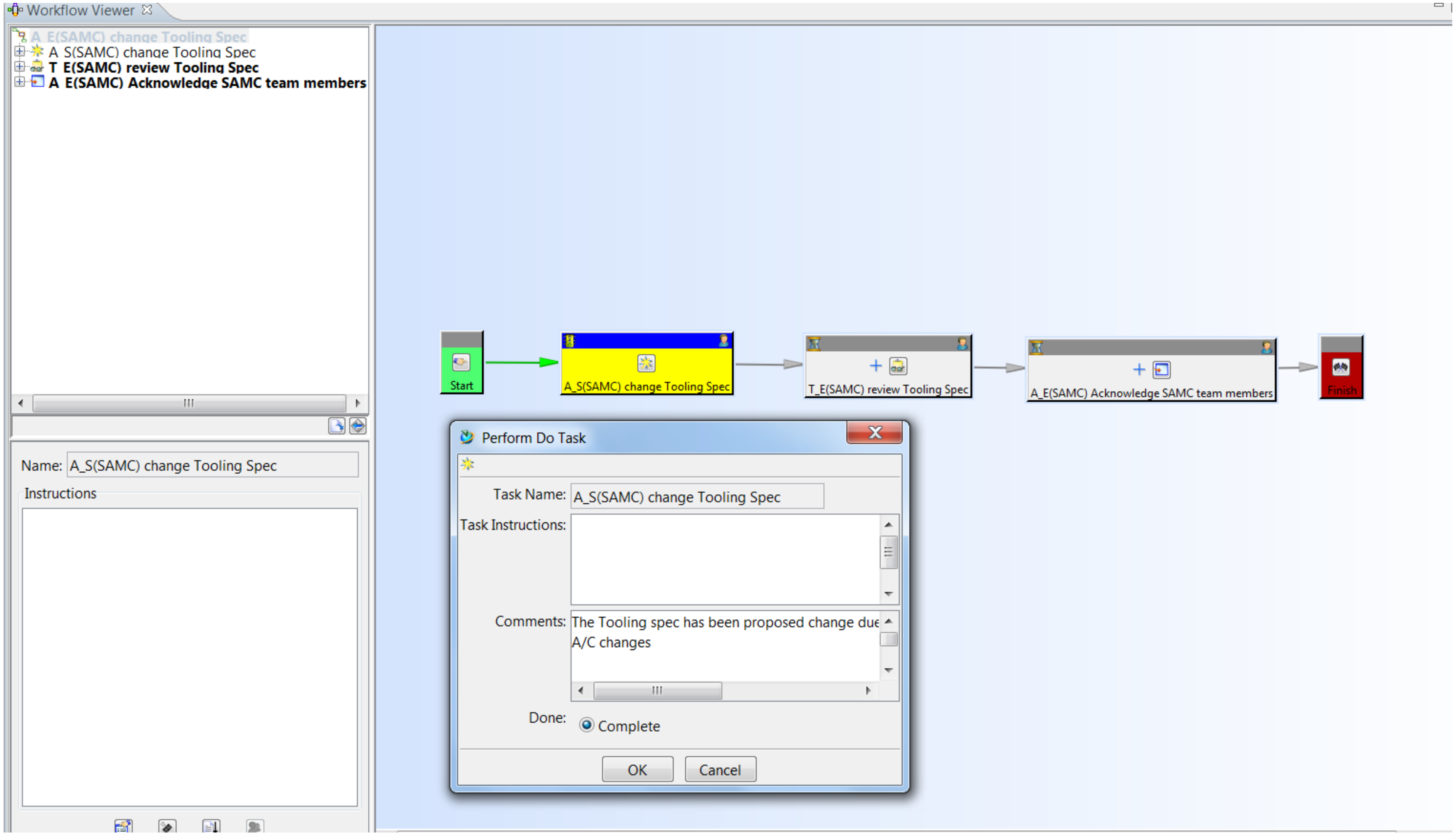
2. The assembly engineer start workflow and assign roles for each task



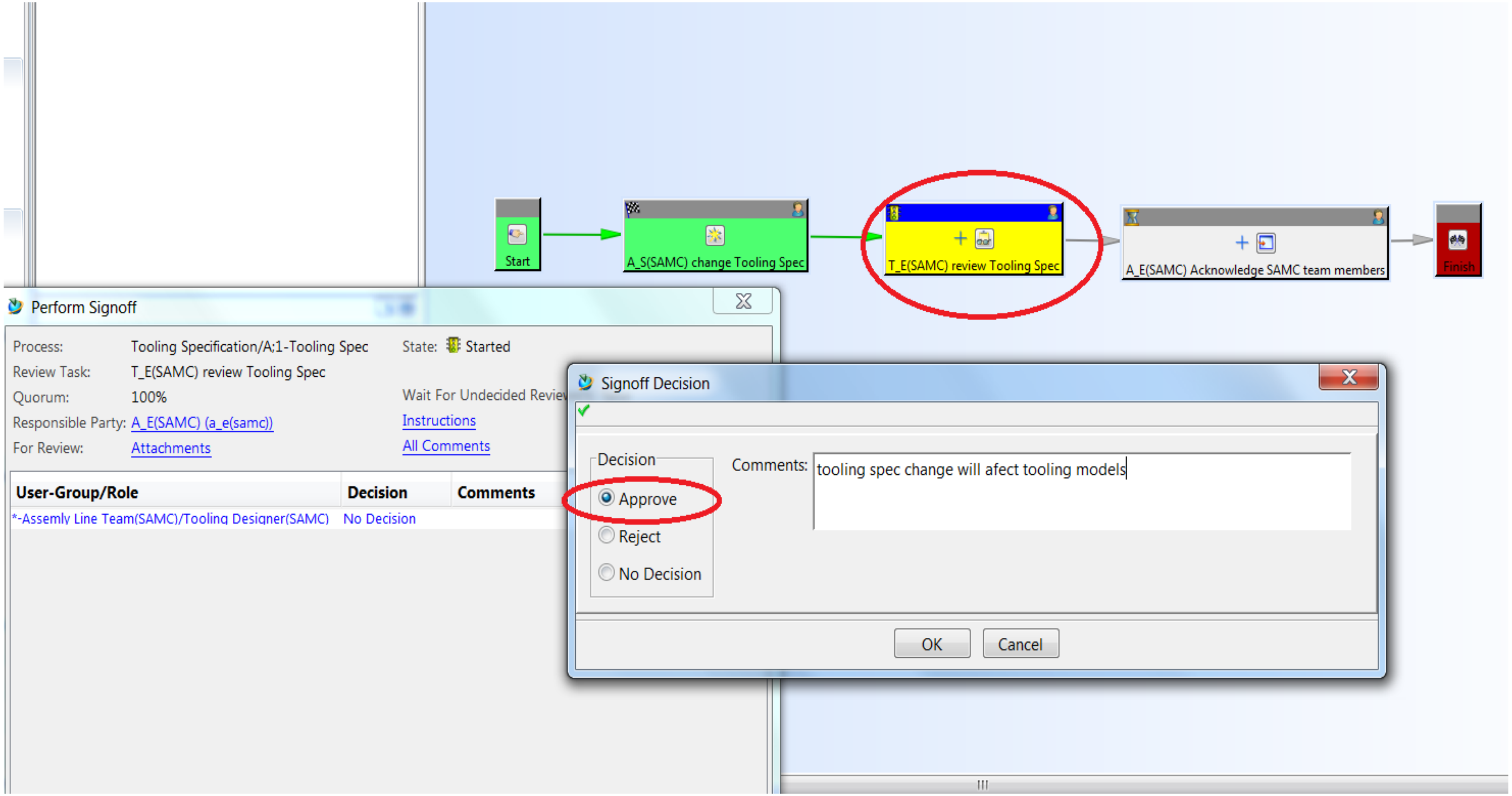
3. The assembly engineer of SAMC modify the tooling spec document



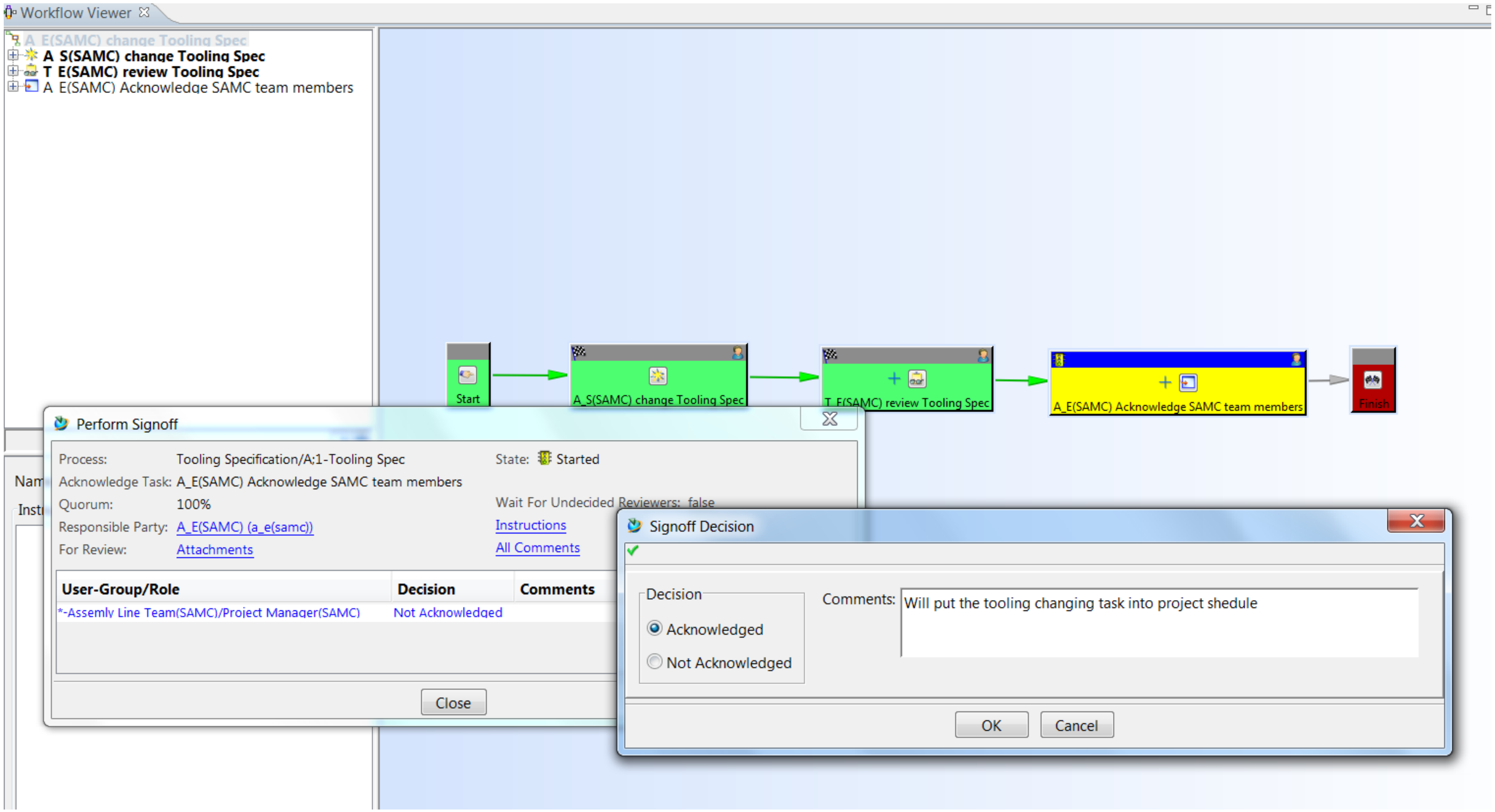
4. The assembly engineer of SAMC completes revise the tooling spec document in the workflow node and transfers the review work to tooling designer.



5. The Tooling designer of SAMC reviews and approve the tooling spec changing proposal.



6. The project manager of SAMC team gets notification of the tooling spec changes.



Appendix F Questionnaire to people work in SAMC assembly line project

受访者的姓名，头衔及所属公司部门 Interviewee’s Name , title, Organisation	
答卷日期 Date of interview	
联系电子邮箱： E-mail Address：	

声明：此问卷调查为某人研究课题的一部分，用以收集关于上飞公司大型客机装配线项目中数据管理与交换，工作流程管理的当前状态，以及改善方向，改进提案的的专家反馈意见。此次的独立调查结果将不会直接与上飞公司的任何工作产生关联。

Claim： This questionnaire is a part of a personal research project which aims to gather experts’ opinion about the data management/exchanging and workflow of the current practice, improvement opportunity in SAMC C919 assembly projects, also to get the feedback of proposed solution. The result of this independent interview will not connect to any work activity of SAMC.

1. 您在多大程度上同意如下的表述，在装配线的详细设计阶段，主要的设计工作是由数据的创建，修订组成的，且工作成果会被固化于各种文件之中？（5=非常同意， 3=部分同意，1=无法同意，请使用数字 1，2，3，4，5 进行评分）
   您的评分：___________

In what extend do you agree such a expression, in the assembly line detail design phase, the majority design work is comprised by data creating/revising, as well as work result consolidated into various documents? (5=Very much, 3=Somewhat,1=Very little, please remark with number 1,2,3,4,5)

Your mark:___________

2. 请估计在生产线细节设计的过程中，各种数据(例如飞机数模，装配线数模，数控程序)的存贮形式（按百分比）：
Please estimate the proportion of data storage types (e.g. aircraft model, assembly line model, NC programme) in assembly line detail design phase (by percentage):

On Platform(e.g. PTC Windchill)在设计平台上（如 PTC Windchill 系统）	
Local Personal workstation 在个人的工作站	
Hardcopy 纸质文档	
Others(please point out)其他请注明	

3. 请你选择上飞公司和供应商的生产线设计团队成员人员主要依赖的数据传输方式(请打勾为确认，空白为不存在)：
Please choose the data/document are transferred methods between design team members of SAMC and suppliers.

(Please tick as appropriate, leave as blank if application is not available)

Via Platform(e.g. PTC windchill)	
E-mail	

Hardcopy	
FTP	
Movable memory device	
Others(please point out)	

4. 在多大的程度上您同意，通过工作平台的数据版本自动控制可以大幅度减少人工消耗和错误发生率？（5=非常同意， 3=部分同意，1=极少同意，请使用数字 1，2，3，4，5 进行评分）
   您的评分：____________

   To what extent do you agree that the automatic version control of data by work platform could largely reduce labour hour and error rate?

   5=Very much, 3=Somewhat , 1=Very little ,please remark with number (1,2,3,4,5)

   Your mark:____________

5. 在多大的程度上您是依赖于已经建立的工作程序和实践惯例来完成在生产线设计的工作的？（5=强烈依赖， 3=中等依赖，1=极少依赖，请使用数字 1，2，3，4，5 进行评分）
   您的评分：____________

   To what extent can you actually rely on established procedures and usual practice to fulfil your job in assembly line design?(5=Very much, 3=Somewhat , 1=Very little ,please remark with number 1,2,3,4,5)

   Your mark:____________

6. 在多大的程度上您同意，在生产线的详细设计阶段，设计循环可以看作是由飞机设计者发起的工程更改活动？（5=非常同意， 3=部分同意，1=极少同意，请使用数字 1，2，3，4，5 进行评分）

您的评分：___________

To what extent do you agree that, the design loop of process of in assembly line detail design phase could also regard as a type of EC (engineering change) which triggered from aircraft designer?(5=Very much, 3=Somewhat , 1=Very little ,please remark with number 1,2,3,4,5)

Your mark:___________

7. 您期望产品数据管理系统可为生产线设计提供哪些功能？(请打勾为确认，空白为不存在)：

What function do you expect which provided by the PDM (product data management) system in the assembly line design?(Please tick as appropriate, leave as blank if no)

Work folders for all teams 为所有团队建立工作文件夹	
Single data source 单一的数据源	
Data/Document version control 数据及文件的版本控制	
Online data transferring 在线数据传递	
EMOB to MBOM converting 从 EBOM 到 MBOM 的转换	
Visualisation of product model 产品数据的可视化	

Project management via workflow pre-definition & control 通过工作流程定义和控制的项目管理	
Others(please point out)其他功能请指明	

8. 在多大的程度上您认为在 Teamcenter 上建立的工作仿真（详见附件 PPT）涵盖了您的需求？(请打勾为确认，空白为不存在,如需评价请写在后面)：
Which functions do you think the Mock-Up on Teamcenter 8.1(in the attached PPT) covered your requirements ? Please give additional comment if you want?

Functions 所提供的功能	Mark 打勾确认	Comment 评论
Functions in Mock-up 在工作仿真中的功能展示		
Work folders for all teams 为所有团队建立工作文件夹		
Single data source 单一数据源		
Data/Document version control 数据及文件的版本控制		
Online data transferring 在线数据传送		
EMOB to MBOM converting		

从 EBOM 到 MBOM 的转换		
Visualisation of product model 产品数据的可视化		
Project management via workflow pre-definition & control 通过工作流程定义和控制的项目管理		
Others requirement(please point out) 其他功能需求请指明		

9. 您期待何种可由信息化环境提供的额外功能以可加速生产线的并行工作流程与协作？
Which extra function do you expect provided by IT environment to speed up the concurrent work process and collaboration in assembly line design?

Your answer 您的评价: ____

____

Appendix G The attachment of questionnaire

Questionnaire
问卷调查

Cranfield UNIVERSITY

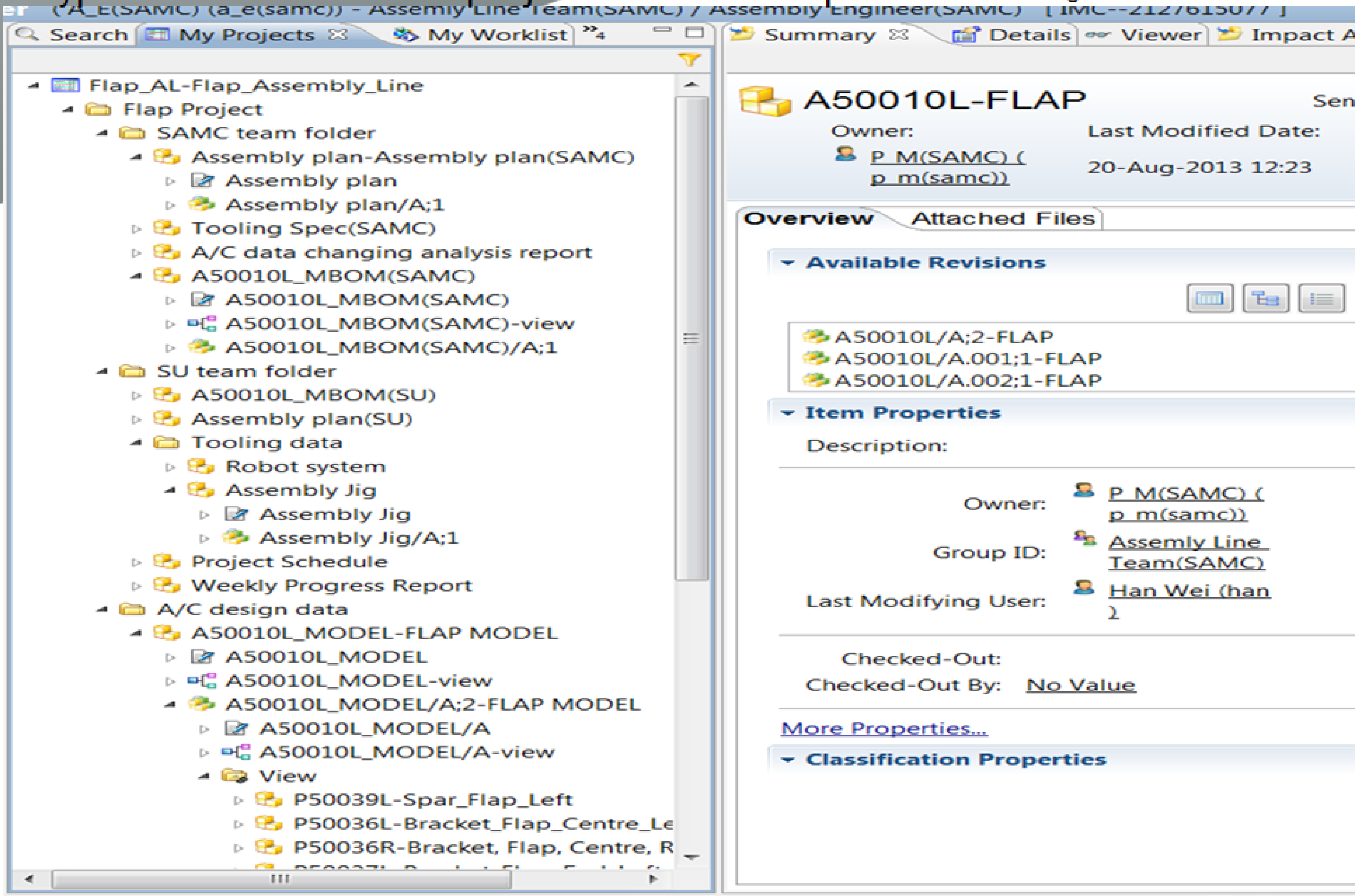
The Proposed Solution and Mock-up On Teamcenter 8.1
解决预案与在Teamcenter8.1上的建模仿真

By Wei Han

www.cranfield.ac.uk

1.为不同项目团队提供结构化的数据存贮与远程在线共享。
The structured data warehouse and distribute online sharing of all types data for different projects and development teams。

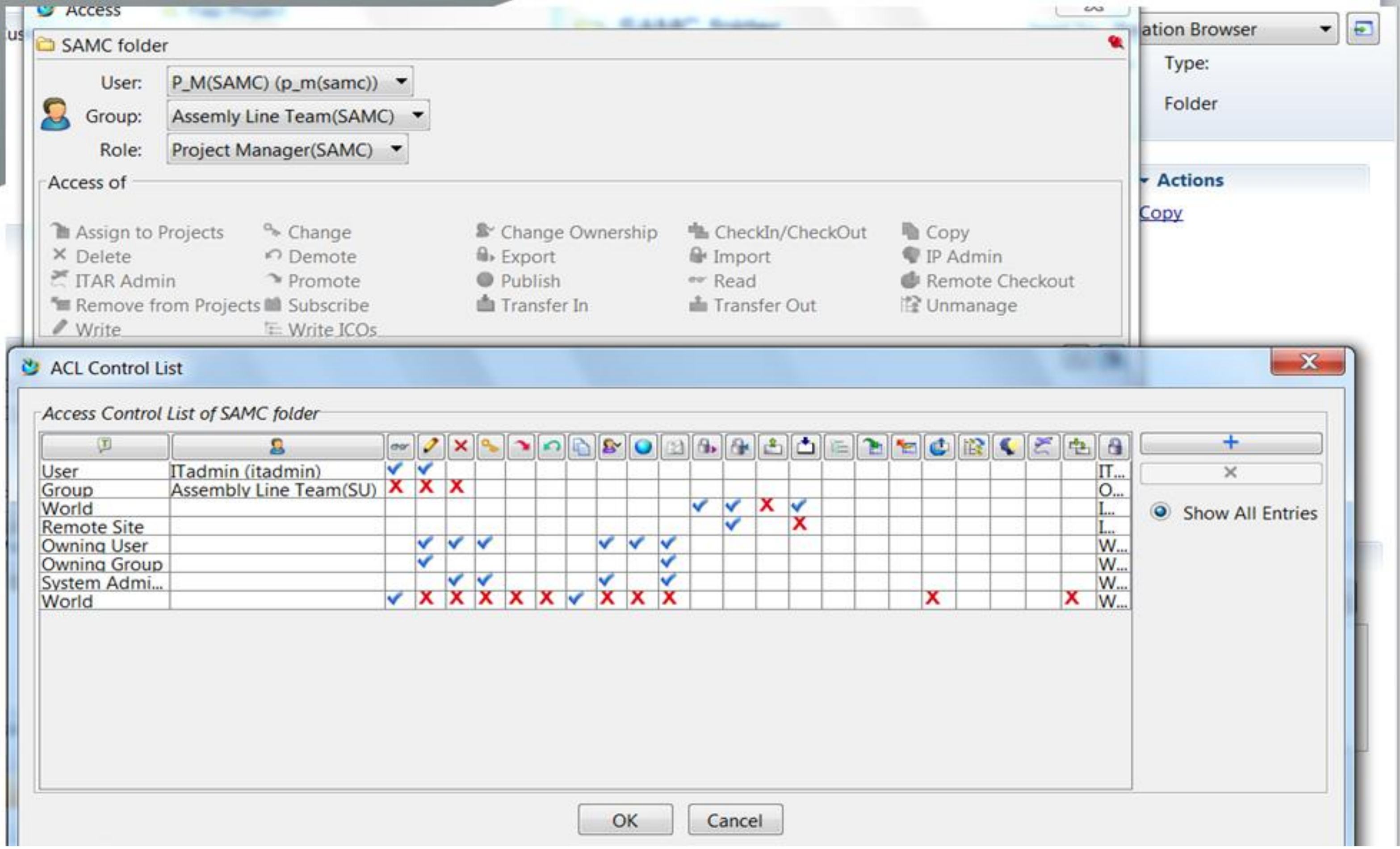
Cranfield UNIVERSITY



By Wei Han - 01 - www.cranfield.ac.uk

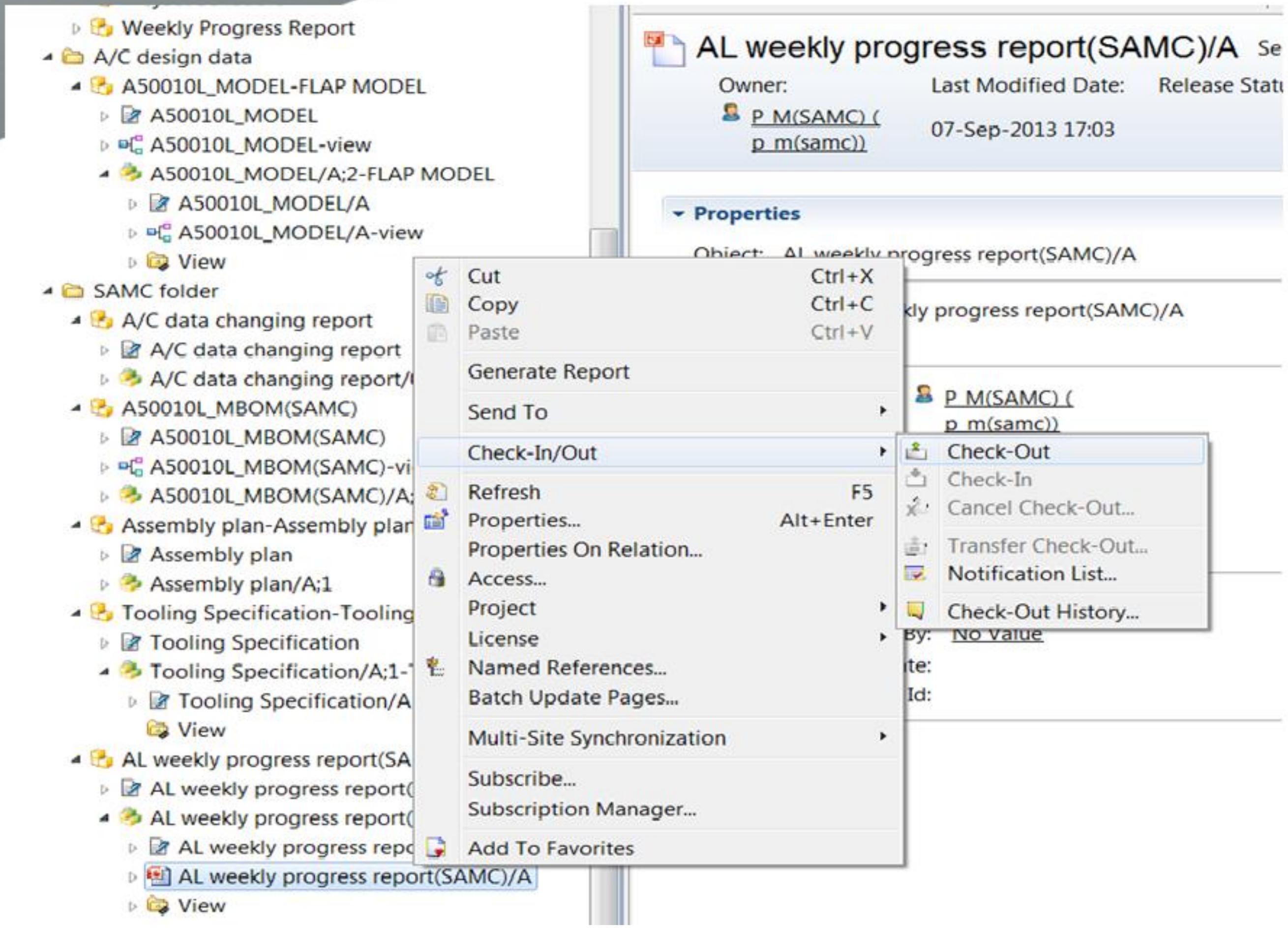
2.可设置用户的文件操作许可权限。
Access control for team members

Cranfield UNIVERSITY



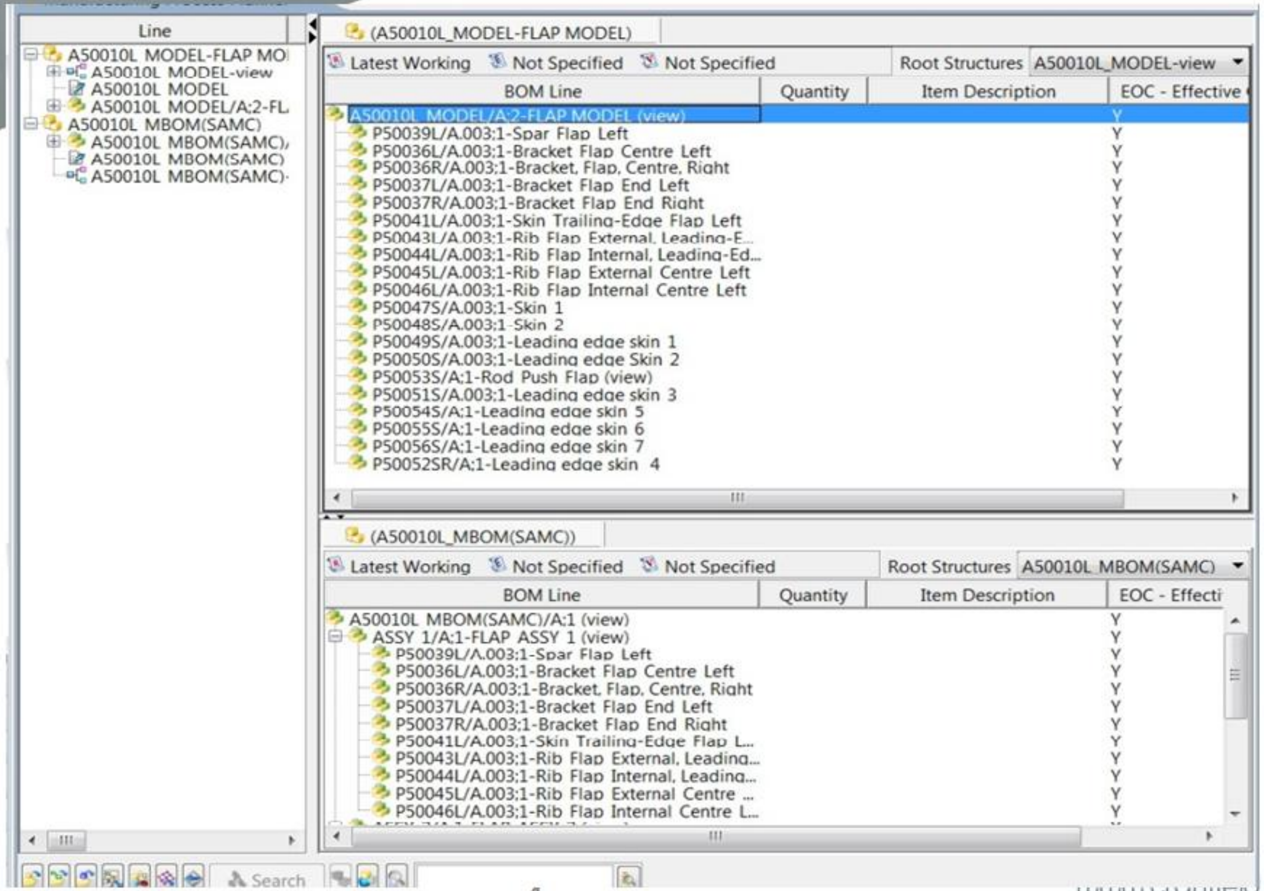
3. 自动版本控制及历史版本存储

Automatic revision Control and historic data Storing



4. 产品构型管理及EBOM-MBOM转换。

Product configuration management and EBOM-MBOM reconstructing



Cranfield UNIVERSITY

By Wei Han

- 4 -

www.cranfield.ac.uk

5. Product model visualisation
产品模型可视化

Cranfield UNIVERSITY