# Concurrent Engineering for Mission Design in Different Cultures

by

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M.S., Mechanical Engineering
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Submitted to the System Design and Management Program
in Partial Fulfillment of the Requirements for the Degree of

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## ABSTRACT

The satellite is a highly complex system due to the tight physical constraints, high reliability requirements, and the scale of the product. Except for some commercial missions, most of the satellites are designed from concept to optimally achieve their missions. Historically, the multidisciplinary team spent several months or even a year to finish the concept design. As the information technology revolution occurred in 1990's, Integrated Concurrent Engineering (ICE) was invented to reduce cycle time and reduce resources but with higher quality. It is a new method of real-time team collaboration based on the quantitative computer-based calculations. It was introduced with significant success by JPL/NASA and The Aerospace Corporation. Some organizations followed in using ICE and also confirmed that the design period was reduced from months to weeks.

Despite the remarkable successes of the ICE application in the United States and Europe, it is neither used nor well known in other parts of the world. The Japanese organizations, for instance, provide complex products and show their presence world wide, but there is no report of an organization utilizing the ICE approach. They applied the concurrent engineering in manufacturing long ago. It is unclear what brought this situation. The ICE approach has been well examined from the systems engineering perspective but not from the cultural aspect.

This thesis analyzes the ICE approach to identify the key factors for successful implementation and operation from both systems engineering and cultural perspectives through the case studies of a implementation failure in a Japanese organization and some successes in Euro-American organizations. Then, the author proposes several ways for successful implementation in the Japanese organization and proposes how the ICE should be approached and be utilized to leverage the design capability of the organization.

Thesis Supervisor: Dr. Donna H. Rhodes, Senior Lecturer, Engineering System Division

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## LIST OF ACRONYMS

CE - Concurrent Engineering
CDC - Concurrent Design Center
COTS - Commercial Off The Shelf
ESA - European Space Agency
ESTEC - European Space Research and Technology Centre
GUI - Graphical User Interface
ICE - Integrated Concurrent Engineering
IT - Information Technology
JPL - Jet Propulsion Laboratory
LaRC - Langley Research Center
QC - Quality Control
RFP - Request For Proposal
SD - System Design
SDO - Satellite Design Office
SE - Systems Engineering

# *Chapter 1: Introduction and Overview*

It has been almost a decade since the beginning of the "information technology revolution". It did not change our life to the fully automated society as some people dreamed, but actually it has had huge impact on our lives and the same in the aerospace industry. Information technology can help not only in improving the performance of an individual's work, but also improving the performance of collaborations in the team. Many organizations succeeded in improving the team performance and even improving the quality of their products with less time and resources by implementing IT tools and methods in their organizations. However, it is also the case that many organizations fail to leverage their performance with information technology. Sometimes they found the best selling tools did not work in their organizations or new high-tech facilities were collecting dust. As the importance and dependency on information technology increases, it is critical to well utilize this technology to survive the world wide competitive situation.

This chapter introduces the research described in this thesis, including problem definition, questions, research objectives, approach, and research overview.

## *1.1. Problem Definition and Questions*

Integrated Concurrent Design (ICE) process was developed by the Aerospace Corporation. Once the success in JPL/NASA was reported, it was accepted with enthusiasm from the aerospace industries in the late 1990's. It has been successfully implemented in some organizations in the United States and in some European countries. However, ICE is not popular in other places of the world, e.g., in Japan where many complex products are developed and competing with the Euro-American companies. Many Japanese companies actually implement concurrent engineering in manufacturing but why not for the design activities? The concept of ICE seems to match well to Japanese culture but why do they not use it?

Actually, a governmental organization , let's name it "organization A" for anonymity in this research, tried but failed to implement the ICE within it. How can this kind of thing happen? How did they fail to manage that? What mistake did they make in implementation of ICE for their organization? Is the ICE basically in conflict with the culture in organization A? Then, how would ICE be modified or how would they improve their ICE implementation process?

In general, how can ICE be modified to fit Asian and Japanese culture? How should ICE process and its environment be perceived to enhance the collaborative design activities in the organizations with different cultures?

## *1.2. Research Objectives*

The primary objective of this research is to identify the main reasons why the organization A failed to implement the ICE approach in their satellite concept design activity. Through the case studies of the organization A and other organizations which implemented successfully, analyses are performed from the systems engineering and cultural perspectives. Analyzing the reference successful cases from the literatures will help to find the key factors for success and what the Japanese organization failed to achieve.

Another objective is examining if the national cultural difference between Euro-American countries and Japan can be the critical factor to divide success and failure of ICE implementation. Then, in case it is even partially true, it is worthwhile to examine "what is the key cultural factor making that difference?" and "how can the ICE can be modified to fit Japanese culture?" to judge if the ICE could be designed to work in the different national cultures. Finally, it will be ended by proposing how ICE can be modified to fit the Japanese culture, and how the organization A could avoid the failure by focusing on the different factors or changing their implementation process.

## *1.3. Approach and Research Overview*

This thesis has the following structure to describe the approach of this research.

1. **Introduction and overview:** The motivations and the objectives of this research on how the ICE can work in the different cultures are stated in this chapter.

2. **Literature Research:** The public literature is widely reviewed to identify the characteristics of the ICE and how the Euro-American organizations, e.g. JPL/NASA, LaRC/NASA, ESTEC/ESA, Astrium and other anonymous organizations successfully implemented and used ICE. Also, the review and analysis are performed on how Japanese manufacturing companies work efficiently and effectively without using ICE and the cultural background which enables the different work style. This aims to help identifying how this different work style brings the easiness or difficulties to implement and use the ICE approach.

3. **Research Method:** It describes the research methods used to collect data and the types of the data collected from organization A. In addition, it states the approach to analyze the data and the limitation of findings because the data is provided from one organization.

4. **Case study:** The main case is described based on the technical data and the result of interviews provided from organization A by focusing on;

    - What did they expect on ICE approach?
    - How it could work in their organization?
    - How did they try to implement ICE approach?
    - What was done wrong by management in implementing the ICE approach?
    - How are they working for satellite concept design now?

5. **Reference cases:** To compare with the main case, the successful cases are described from reference literatures. As no paper or thesis reports all the characteristics focused on the main case, some are merged to assess all of them.

6. **Case Study Analysis:** The main case is analyzed from both systems engineering and cultural perspectives to identify the answers to the questions stated in chapter 1. The detailed analyses are done by categorizing the issues they used to implement the ICE approach by comparing the successful reference cases described in chapter 5. Then, some proposals are made to avoid the failure and to modify the ICE approach to fit their culture smoothly.

7. **Summary of findings and conclusion:** This final chapter summarizes the findings in each chapter and the conclusion of this research.

# *Chapter 2: Concurrent Engineering in Design*

Concurrent engineering has been used for some time even before the term "concurrent engineering" was created. Its core concept is that all the stakeholders in the entire development life cycle, including customers, sales, design engineers, manufacturers, test engineers, etc, work together in close communication especially in the design phase. This helps to improve the quality of product design which will reduce development cost by reducing costly rework in later phases and will reduce the schedule.

Coffee (2006) discusses this concept as adaptable not only to manufacturing but also to concept design with Integrated Concurrent Engineering (ICE). Requirements, constraints and any other information to be considered are discovered, structured, solved and transferred into system concept and system design. These tasks can not be done as straight forward. All the tasks are done repeatedly and information exchange among team members happens periodically when needed. ICE process and environment helps a team enhance its capability to drive these activities smoothly and efficiently. Under this concept, a concurrent design environment has been installed in some organizations that specialize in developing complex spacecrafts during the last decade. But this is the case only in the United States and Europe. In other regions, especially in Japan where companies develop many complex products, no reports about successful utilization of ICE or similar concepts have been found in an extensive literature research. Examining the characteristics of the ICE approach and required capabilities to the organization to let the ICE works will help to explain this situation.

This chapter reviews what the ICE is (section 1) and how it is implemented in practice (section 2). The role of CE is also discussed with a broad view that is differently implemented in different countries, along with how the cultural difference or work styles influence the early phase design activities if there are any (section 3).

## *2.1. What is ICE?*

It is clear that skilled and talented engineers are essential for a well designed system concept regardless of the process or tools they use. However, well defined process and procedures with supporting environment can enhance the team productivity and quality of the output. ICE is a methodology to integrate individual work and communication among the concept design team and other stakeholders. Evolution of information technology enabled the realization of ICE. Parkin, et al (2003) defined ICE as a real-time collaborative process:

> Integrated Concurrent Engineering (ICE) is a real-time collaborative process in which a multidisciplinary team discusses a design or analysis problem while concurrently conducting quantitative, computer-based calculations.

They also figured out 5 critical elements for successful implementation of ICE.

- A well-defined set of standard information products for output
- Network-linked tools to eliminate manual reformatting of inputs and outputs and to facilitate nearly instant quantitative engineering.
- Well-understood procedures for real-time collaboration; concurrent quantitative engineering and qualitative conversation
- A standing multidisciplinary team skilled in the tools and methods
- A facility supporting the hardware, software, and human resources

Actually, these reveal two important points to be considered. One is how well the design team members communicate to each other in two channels in real-time; design parameters through design tools and integrated network infrastructure, and qualitative information through face-to-face communication. Another is how well the organization improves capability and usability of integrated information infrastructure, design process, and adaptability and readiness of members to work under ICE process and infrastructure.

**What are the merits of ICE?**

The main advantages of ICE compared with the classical approach can be condensed into three points.

- ICE shrinks development time in the early design phases drastically, often said from months to weeks.
- Lean design process improves the quality of design and requirements with less time and cost.
- Quick design cycle turnover results in people working smarter, and improves the design process and design skills of engineers.

In classical design process, occasional meetings are the only chance to exchange information and redirect their further tasks. It usually takes at least several days. During that interval, people are just waiting for the next meeting after they finished their parts in a design cycle; otherwise team members update their data at their own timing and raise serious issues on revision control. McManus (2002) reported that 40% of time spent in product development could be classified as "pure waste." Worse than that, information and parameters they used for their own analysis or design can be already updated. Long intervals for the information exchange are a serious source of low team productivity. Intensive and close communication has been the source of competitiveness for Japanese companies in product development and manufacturing. ICE can improve the communication capability in a team by utilizing the growing performance and capability of information technology.

ICE directs the team toward system optimization through integrated information system and instant communication. ICE environment makes it easy for participants to have frequent ad-hoc discussion and reduces the chances of spending a long time under wrong assumptions or old data. Information integration prompts participants to think holistically using system thinking. People normally tend to hide too much margins in their disciplines and raise the risk of designing a locally optimized system, but data transparency forces them contributing on total system optimization.

ICE leads a team to continuous improvement in personal skills, system models, design process, and design environment. Also people have to work smarter to answer questions and to provide data for analysis from others. They are constantly under pressure to improve their skills and tools for quicker reply. Increasing the number of design activities in short cycle with ICE approach provides a good chance to improve the design process, parametric system models and other support systems. Furthermore, people have more chances to adapt themselves to the ICE design process and improve their required engineering skills within a shorter time.

Additionally, it is not easy to implement an ICE approach into an organization smoothly. Much investment is required to integrate people, process and information infrastructure. Many reports pointed out that people have to accept use of a new method of working which may require the difficult decision to change their behavior and step away from their experienced working style. Design process and supporting environment should be prepared well for smooth implementation. People should be trained to work under the new process and environment. Too much focus on tools may limit their analysis within the capability of the tools. These may also increase the overhead cost and reduce the flexibility, yet these are the key to enable ICE implementation and substantial investment is required. Without proper investment on supporting tools and environments, the design session will be slowed down or disrupted because of cumbersome data transfer among the team members, operations of design and analysis tools, heavy documentations after the sessions, and other factors.

## *2.2. ICE in practice*

There is continuous pressure to reduce development schedule from the market and on improving design quality in early phases to reduce the costly rework and redesign in later phases by front loading. In the spacecraft business, the long development time is one of the weak points. While the business plan looks good in the beginning, their business ecosystem can be completely changed and new technologies or new competitors force them to change their original plans. Governmental and academic programs require manufacturers to respond to their request for proposals (RFPs) quickly, sometimes in 30 to 60 days, with high quality designs to win the contract competitions. Academic and governmental organization themselves are also in the same situation. Scientific findings are in an international time race and need a high quality proposal to win the internal competition. Responding to these challenges, some organizations have tried and succeeded in implementing an ICE approach especially for spacecraft design while they faced several hurdles to overcome.

The Aerospace Corporation's Concept Design Center (CDC) is one of the oldest facilities that has implemented ICE in practice. Aguilar, et al (1998) reported CDC is developed and implemented for the Product Design Center (PDC) in JPL/NASA and tailored to other organizations. Some additional facilities in Europe have also been established based on their original but similar concept to CDC. While these facilities look similar and share almost the same objectives with the original one, they are developed, implemented and operated in different situations with different capabilities. Through reviewing reports, how ICE is implemented and worked in practice is discussed in this section. The following organizations in various situations are focused on;

- Product Design Center (PDC), JPL/NASA
- Concept Design Center (CDC), The Aerospace Corporation
- Concurrent Design Facility (CDF), ESTEC/ESA
- Satellite Design Office (SDO), Astrium
- Space System Concept Center ($S_2C_2$), Thechnische Universitat Munchen
- A few anonymous organizations and facilities

### *2.2.1. Design Process and Procedures for the ICE / CDC*

Each organization has different objectives to employ ICE. Each organization is in different circumstance, with different organization structures and cultures. It is natural that each organization follows different steps and timeline to drive ICE design process. However, ICE process can be divided commonly into three sub-processes; setup, design sessions and post-session as follows.

**Setup:** Before starting the actual design activity, there are many things which have to be prepared well because design sessions are the chance for intensive team work within a short period. The design session will stop if there is any lack of information, resources, and capabilities in the team. Once a design session stops and requires long interval to restart, the merit of intensive design session will be diluted. Therefore, the team should understand;

- customer requirements or specific needs
- list of required system functions and specialists in the related disciplines
- scope of the design activity
- capabilities and limits of tools and specialists
- list of stakeholders and initial inputs from them

The initial set of customer requirements or needs gives the team some estimate of how hard the technical challenges are and in which fields. This also affects what tools can be used and what tools have to be developed or modified to cover the estimated design and analysis. The timeline of the sessions and the depth and coverage of technical design has to be estimated in this process because the design sessions are usually performed in a tightly compressed schedule. The excess can not be absorbed in the long interval that the traditional approach has. Team leader, system engineer, project manager, customers and engineers in the key subjects in the mission need enough communication for the reasonable estimation of total work load.

Therefore, this process plays a very important role in ICE. Even though they have experienced specialists with social skills, poor setup will result in a difficult time. The time spent for this sub-process varies widely between 1 to 8 weeks depending on the scale and reusability of experience, but normally 3 to 4 weeks before the session starts.

**Design sessions:** This sub-process creates most of the value of ICE. The key factors, aside from the personal skills, are utilization of integrated working environment and communication environment through physical collocation and an integrated information system. Schedule shrinkage is mainly achieved through this sub-process.

Actually, a design session is not the same as a meeting. Team members get together in the same room to communicate, but do it only when and with whom they need to. Engineers perform their individual work as if they are in their home base. This is very similar to the "open office" concept employed especially in Japanese organizations. Under the "open office" concept, employees do not have their individual cubicles. Instead, a team places their desks like an island in the same room which lets all the group members see what others are doing and makes it easy to start ad-hoc discussions when they want to. One of the differences, obviously, is the integrated information environment. Quick responses to the emerging questions drive design activity faster. Organized design parameters allow instant communication through the network. Visual aids help everyone share his or her problems with others clearly. IT helps communication a lot and this is a strong advantage of ICE.

However, most of the reports disclosed that the biggest change brought by ICE is from involvement of customers. Formerly, customer requirements are given and are sometimes unconditional. In concurrent design sessions, any team member can ask questions about requirements to customers. What happens is that requirements are challenged by the team with the "facts" of trade-offs and analysis. This means ICE added a new role for the customer; collaborate with team members to achieve the mission objectives.

ICE also requires new roles to run the sessions. Besides the participation of customers and other related stakeholders such as sales, management, testing, manufacturing, etc., a team needs a project manager, team leader and system engineer. In this context, the team leader is the organizer and conductor of a design session. He or she is expected to get things on a roll rather than designing the system. Mager, et al (2000) defined the role of team leader as;

- moderate the sessions and control technical system aspects in parallel
- control the product tree
- monitor the system design compliance with system requirements
- identify options on system level
- moderate discussions in case of interface conflicts

- generally the technical communicator and moderator for all disciplines between the sessions

Project manager is an observer and shows the policy and direction of the mission. Each design session lasts between 2 and 4 hours on average. Interval and the entire period vary according to the objective and the work load. Normally, sessions tend to be held everyday for 2 to 10 days. When they use high-end tools for detailed design and analysis seamlessly followed by manufacturing design, the degree of real-time design and analysis are limited and engineers have to do their individual homework between sessions.

**Post session:** ICE can drastically reduce the development time, but team work load can not be reduced with the same magnitude. The team has to work intensively in the short term. A lot of work should be done in design sessions and their intervals. This means that the results have to be documented in short term. While a set of design information is created in the sessions, it is meaningful to write design rationale, basis of trade-offs, and so forth.

It greatly helps the team if they use an automatic documentation system and design process; output of the design sessions and memos are converted into the report automatically and the team does not need to write the report from scratch. Adding a "documentation" role in the team will also help the team to keep their progress tracking.

### *2.2.2. Facilities, tools and network; Integrated Design Environments*

In general, facilities for any specific purpose should be designed to help the intended work behaviors of users. As mentioned before, objectives of ICE have significant overlap among the organizations who have implemented them. It is no wonder that most of the design facilities have similar features; a main discussion table at the center of the room, projectors connected to any displays, PCs with design or analysis tools operated by specialists, a data storage server, network, a small sub discussion room, and video and teleconference equipments. Figure 2-1 shows some examples for physical layout of a facility.

The first thing we can recognize is that visual aid is highly utilized in CDC. Multiple projectors are installed to help instant perception and deep discussion. When specialists operate their tools in the facility, they can show the result of design or analysis instantaneously to help them explain them to other team members. It also helps explain their points focusing on not only on their own field but also on systems and other related disciplines at the same time.

The tools they use for design depend on the needs of organization, but all of them selected are what the specialists use daily or organization standards for which they sometimes face difficulty in managing the data exchange interfaces. One exception is that all the organizations used the spreadsheet for design parameter management. This is mainly because even the new team members are familiar with it and have high visibility of multiple numbers at a glance.

The most important things to be considered are

- What are the expected input and output parameters?
- How do we exchange information among the tools?
- What experience and skills do the specialists have?
- What capabilities do the tools have for the real-time design and analysis?
- How well and how quickly can the specialists handle the tools?

The answers to these questions above are the key for organizing and driving the session smoothly. They are also the key to understand the limitation of design sessions. The more ambiguity in design parameters or less data compatibility you have, the more you have to depend on the experience of engineers. Complex interface of tools and capability of engineers has great impact on the speed of design cycle.

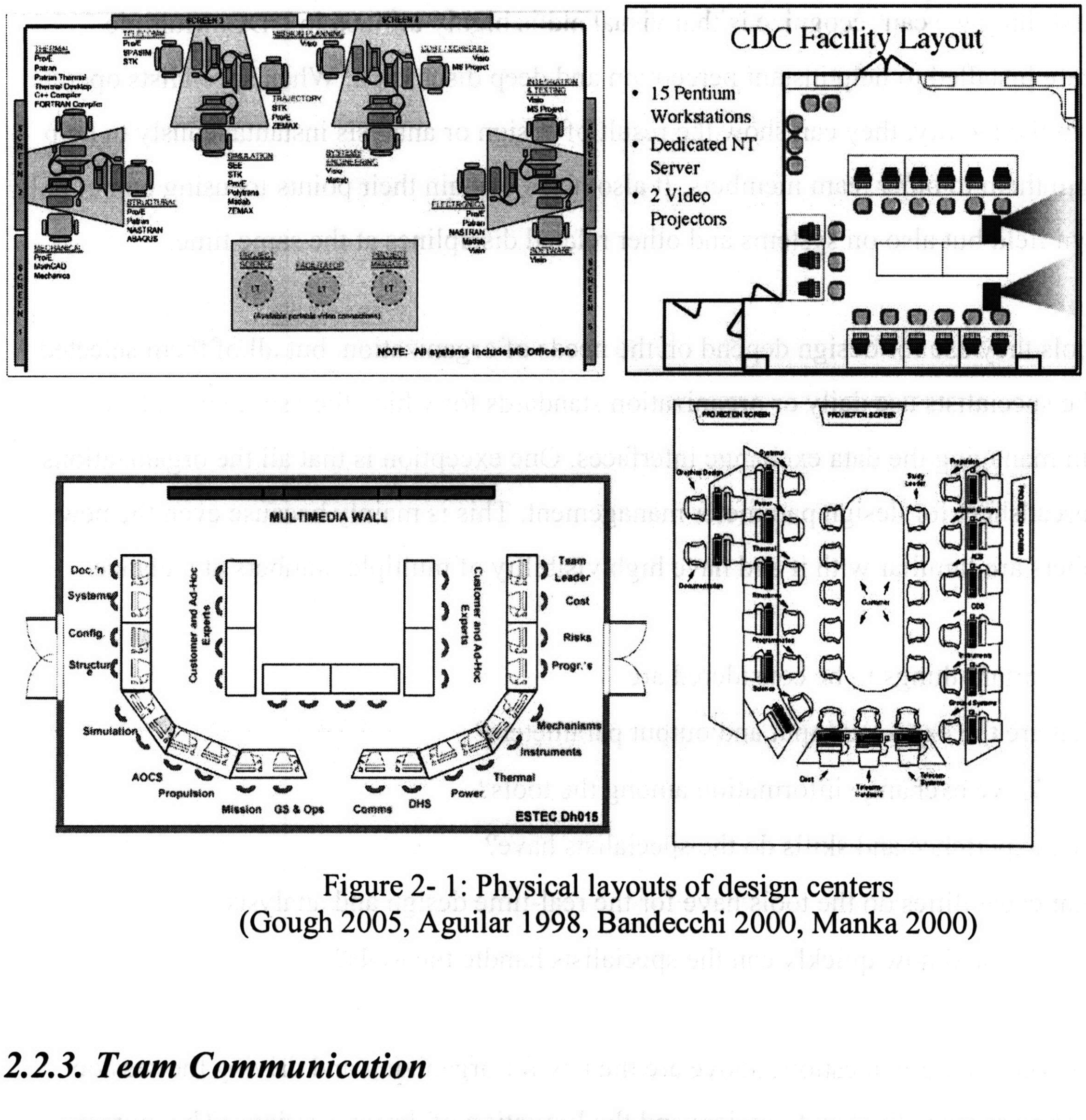

Figure 2- 1: Physical layouts of design centers
(Gough 2005, Aguilar 1998, Bandecchi 2000, Manka 2000)

### *2.2.3. Team Communication*

All the organizations operating an ICE reported that the team is the most important element of ICE. Actually, design activity is performed by a team. Tools, process and other environments are needed to support it. Aguilar, et al (1998) reported that the initial CDC is developed under the concept of centralized design process, like an "expert system", which a small number of system engineers control and design with an integrated tool. They figured out it does not work well. In this process, system engineers gather and integrate necessary information into a spread sheet and operate it for design. It greatly contributed to reducing the design time but raised some issues. Engineers are not involved in the process after they gave the tools and models to the system engineer, and he or she can misuse the tools without deep understandings in the technical fields. Furthermore, the model is kept rather simple and its capability can be limited because it is designed to be used by the system engineer. In other words, this tells us that the concept design activity requires continuous adjustment of the tools and models through deep commitment of engineers.

Next, the distributed design process is developed. Even though leadership is performed by the team leader, system engineer or project manager, each specialist has responsibility for his or her own field and he or she can communicate with each other independently. They are motivated to contribute continuously in the design process. Then, new phenomenon is observed with this change. Specialists start direct discussion and ask questions of customers challenging requirements. Feasible and clarified requirements are created in real-time and this reduced much time. This means the ICE created an open design environment by allowing team members to have a holistic view. It helps fast and certain identification of risk areas and design drivers. Quick decisions are made on potential options in brainstorming trade-offs without long intervals. Now they can see the design cycle and can contribute to driving it. Knut (2000), Bandecchi (2000) and some other leaders reported this new improvement with some surprise.

Physical layout of the ICE facility is designed to fit for distributed design process. In most of the facilities, PCs for specialists are placed toward the wall. Specialists show their back to the project manager, system engineer, team leader and their customer when they are doing their individual work. It is actually easier to communicate with other specialists than those administrative members at the center table. Specialists can do their individual work in their place and join the main discussion if necessary. When needed, they just turn their chair to center of the room. This easy and smooth switch over is a key for the integration of communication and individual work.

### *2.2.4. Success Factors for ICE Process Implementation*

It is not easy to smoothly implement ICE within an organization. ICE does not work in a vacuum. It requires motivation to change the design process from a classical process, and having right people, right supporting tools, enough investment, and appropriate transition into the new design paradigm. Missing even one of these is critical to successful implementation.

The starting point is to understand what ICE is. It is not the ultimate or one-fit-all design tool. Each organization has to have enough motivation and goals for it. The objectives and goals should be measurable in regard to how much they are achieved. Just saying "ICE reduces time and cost with better quality" is not enough. Stakeholders have to be convinced why they should use ICE for a solution and what problems will be solved with ICE. Otherwise, people hesitate to expand their resource and to change their behavior.

Team members also need motivation. Given the involvement of skilled and experienced engineers and managers is essential, their experience of success can be a barrier to change their working behavior because they established their reputation based on their own work style and know-how. Team members have to be well educated in the ICE design process, their personal responsibilities, requirements for their tools, their subsystem models, and real-time communication.

The design environment, including what tools and models are to be implemented, is based on what they can do but not what they should do. Engineers are reluctant to adopt new work procedures or tools especially the time consuming high-end tools. Tools are to be selected by engineers who use them as long as they support the process and engineers. The important thing is that tools and environments should let engineers feel comfortable to work in the session as if they are in their home base.

At the bottom line, implementation of ICE should be built with enough preparation and practice. A quick big leap which easily makes engineers confused should be avoided. Team members including leaders need some time to handle design sessions, new environments and the whole process. Thus, substantial investment of resource and time are required.

## *2.3. Concurrent Engineering in Different Cultures*

Here, I extend my scope to how concurrent engineering is used not only in design but also in the whole system development life cycle. Actually concurrent engineering is used in a different way, especially for manufacturing, in Japan compared with Europe and the United States.

General differences in the usage of CE are discussed in 2.3.1. Then, it is followed by communication and IT infrastructure issues which will help to understand what points of Japanese working behavior may conflict with ICE concept in 2.3.2.

### *2.3.1. Characteristics of Japanese Manufacturing Industries*

Parsaei, et al (1993) and many other papers mention that 70 - 80% of system lifecycle cost is committed in early design phase. Thus, front loading is in the limelight. Implementing high quality in the system in this phase drastically reduces the system lifecycle cost. This is achieved through designing a system with consideration of all the requirements and constraints through system lifecycle; manufacturing, testing, deployment, operation, disposal and renewal. In this context, "integrated organizations" with high capability of communication, information sharing and collaboration among employees and groups have great advantage to "modularized organizations" with segmented structures to maximize the performance of their own specialties. Clark, et al (1991) discuss this is one of the sources of Japanese automotive companies' growth in '80s. Aoshima (1998) discusses the three unique characteristics of Japanese style concurrent engineering compared with recent "IT environment" based concurrent engineering as ICE/CDC. Some articles discuss two of them as having some relationship with team design activities. They are "development phase overlap" and "integration through entire development cycle".

**Development phase overlap**

Front loading is executed by information input from engineers involved in later phases to earlier phases. Clark, et al (1991) shows some Japanese manufacturing companies get feedback from the later phases by overlapping their activities, say, they run a few phases in parallel. Engineers in earlier phases give their intermediate or rough output continuously to the engineers in later phases and they start their own work before the predecessors are finished. The risk of changes in earlier phases is mitigated by manufacturing know-how and intensive communication between phases to minimize the impact. This also means that engineers in later phases accept some ambiguities in outputs from the earlier phases. Aoshima (1998) reported the product design is sometimes changed even just before the mass production in the extreme case.

In comparison, each development phase is usually finished before starting the following phase in the United States or European countries. The phases rarely overlap. Front loading is only made through giving information feedback based on experiences of engineers. Aoshima (1998) revealed that these differences between Boeing B767 and B777 development activities in Japanese companies as sub-contractors. Development process for B767 sub-system ordered to Japanese companies is lead by each sub-contractor. On the contrary, that of B777 is totally controlled by Boeing. The difference of the development process is shown in figure 2-2. While Boeing intensively investigated Japanese development process, overlap among the phases is not observed for B777. The difference of total development time is explained not because of the overlap but because of the process change and introduction of 3D CAD.

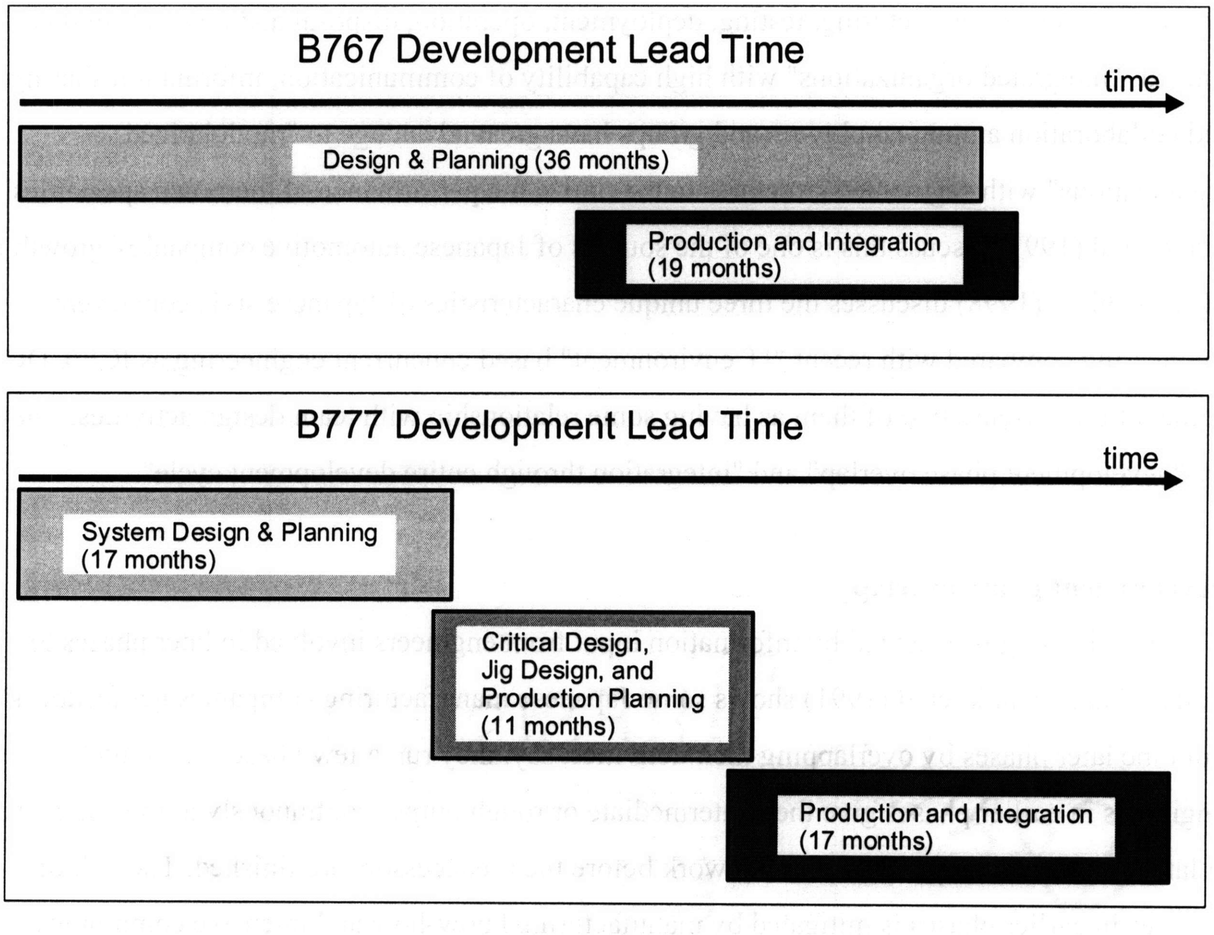

Figure 2- 2: Development Lead Time for B767 and B777 (Aoshima 1998)

**Integration through development cycle**

In a traditional system development process, the system is decomposed into components through design phases and integrated through production and integration phase. In every design phase, the system is decomposed into the small elements and design tasks are clearly allocated to each engineer. Then it is integrated after all the tasks are done. However, Japanese manufacturing companies tend to perform integration activity from the beginning of the phase. All team members work with intensive communication under relatively ambiguous interfaces and personal responsibilities.

### *2.3.2. Communication and IT infrastructure*

As introduced in the previous section, strength of Japanese manufacturing companies are mainly brought by intensive communication. They also handle ambiguity and changes well through development lifecycle, and continuous integration activities in a team with unclear interfaces and responsibility among the team members. These characteristics do conflict with the concept of ICE used in the United States and Europe because it is basically intended to enhance communication among the team members with clear task allocation, clear responsibility allocation and clear interfaces. Tools enable real-time responses to questions from others but they require defining tasks performed with the tools. Network and shared spreadsheets integrate system information and enable instantaneous communication but they require clear interfaces. All the team members have to have their own responsibilities to run design sessions. ICE, even partially, compensates the communication weakness of companies with individual work driven culture. If a company wants to implement ICE to enhance communication and reduce design cycle time, all these three conditions are necessary.

After extensive literature research, no report was found about Japanese organizations which leverage their real-time team communication capabilities for design activity via information technology. Instead of following ICE-like concept, they utilize a centralized design tool like an expert system for system engineers, corporate wide knowledge management system, or design tools used in concept design for each specialty as detailed in Satoh (2001), Kawaguchi (2006), Nishigaki (2002) and Amako (2002). The reason is not clear but the high capability of team communication leads them off focus from improving their communication capability.

But, don't they really benefit from an IT based design environment in terms of team communication? In 1980s, Japanese companies had strong reputation about high capability and quality of manufacturing. High performance team work and intensive communication were the source of the competitiveness. Proceeding the development phases with uncertainty in design was the source of rapid development with high quality. Is there any chance ICE/CDC can leverage the design capability in Japanese organizations?
This question will be discussed in the subsequent chapters through the case study described how a Japanese organization failed to implement ICE for a satellite concept design.

## *2.4. Summary*

Clearly, ICE is not a universal or one-fit-all tool. It requires adequate team, process, tools and infrastructure to implement ICE concept into CDC and run it successfully. It also requires substantial investment on supporting tools and infrastructure, education of team members, and motivation to pay these efforts for design process changes. Forming the motivated and flexible minded team is the key to run CDC while semi real-time design tools and infrastructure with advanced IT are the key trigger making ICE feasible.

The other important point is that most of the organizations that successfully implemented ICE emphasized that wastes in team design activity are reduced and customer requirements are refined for better missions and system designs by customer involvement. Well implemented ICE drastically enhances team communication with clear task assignment and interfaces. It strongly compensates the weak point of Euro-American style design activity compared with that of Japanese style. The question left here is: Is ICE/CDC able to be implemented in Japanese organizations to support design activities? This major theme will be discussed later through the case study.

# *Chapter 3: Research Methods*

All the cases about ICE and CDC in the published literature are the stories in the United States and European countries, and no report is found for Japanese organization while they are considered as very proficient at concurrent engineering in manufacturing. As Coffee (2006) discussed that concurrent engineering which is widely used in manufacturing is applicable to concept and system design. Why ICE is not used in Japan is an open question. This research tries to reveal the reasons for it through exploring a case which is about ICE implementation failure for satellite design in organization A from both systems engineering and cultural perspectives. This chapter explains the research methods used to collect and analyze the data for the case study.

## *3.1. Research methods overview*

This research examines the key characteristics of ICE/CDC implementation activities which ended up with failure in organization A from both systems engineering and cultural perspectives through a case study. Some success cases in the western country are also partially cited from published literatures to discuss how the key characteristics affect the implementation failure and for effective comparison.

The case used in this research is composed of several steps to implement ICE. The data are acquired from the corporate documents including the results of the activities and interviews from the participants as feedback. To supplement the data, interviews are also performed with the employees who led and contributed to the activities. However, it has already been about 2 to 5 years since these activities were done. Most of the engineers are working in the different section and not using ICE anymore. Their memory of the activities is fading in them. This situation made my interview difficult and it was limited to several engineers.

This research aims to report the key systems engineering factors and process for ICE implementation into an organization and to suggest modifications on ICE to fit Japanese culture; at least to the organization in the case. Please note this exploratory research intends to introduce the lessons learnt, but not the basic theory due to the several tight limitations explained in section 3.4.

## *3.2. Research case and data collection*

Organization A is focused on this research because of the data accessibility and availability among the companies and organizations in Japan. There are only a few governmental organizations leading satellite development, and most of the specific names are encoded to simple symbols to keep the anonymity of the data source.

The activities in this case study are as follows;

1. Two consultations by an experienced engineer from the United States
2. Successful trial for satellite system concept design session tracing the design already built with classical process
3. Successful trial for real satellite mission analysis in very limited disciplines
4. Unsuccessful trial for real satellite concept design in full scale which could not prepare sufficiently to run the design sessions

For better understanding of these steps from systems engineering and cultural viewpoints, some successful cases are introduced as reference cases while none of them covers its full story. They are merged to cover all the discussion areas. Due to the data accessibility, those reference cases are cited from published literatures.

As mentioned in the previous section, most of the data is acquired from the documents provided from the organization. These data can be classified into two categories. The one is activity reports and intermediate documents for each step, which explain the action plan, action they took, tools and environments they developed, the result of activity and suggested future work. The other is interviews and feedback for each step from the participants, which includes 'pros' and 'cons' of the process they took, suggestions for further steps, general comments and impressions about ICE process. Data format and contents lists are not unified in the steps because each implementation step is driven by "trial and error" strategy. Data are sorted or analyzed to fit the objective of this research.

## *3.3. Data Analysis*

The data analysis was performed heavily for the main case focusing on the key factors observed by comparing the main case and the reference cases. Although this research is to discuss the cultural aspect on the ICE approach, it is quite difficult to completely separate the influence of the root issues upon the organizational systems engineering capability from the cultural background. The results of detailed analyses on the root issues are also aggregated and summarized from these two perspectives.

The detailed analyses are performed by focusing on the seven categories as below.

- Goal and Strategy Definition
- Stakeholders' Engagement and Support
- Team Building and Management
- Design Process Identification
- System Model Definition
- Real-time Design Tool Development
- Implementation Process

Based on the result of these analyses, the proposals to avoid the implementation failure and modification of ICE approach itself for the smooth implementation are discussed.

## *3.4. Limitations of findings*

Given the space industry has very small market in Japan and most of the satellites developed by Japanese manufactures are ordered from their government, the space industry may have the different characteristics with other commercial industries which sometimes have strong presence all over the world. While the organization in this research has Japanese culture and similar product development process in it, their strength, weakness, and business ecosystem and dynamics will be different from others. Therefore, the lessons learned of this research may not be applicable for other industries when they try to apply ICE concept into their organizations.

The number of case and interviewee are limited. Due to data availability and time constraints, this research is based on the single case from single organization. Even though the case contains several design and ICE implementation activities, the similar activities in the other organizations are not compared and the diversity is low. Additionally, even in the same organization, some lead system engineers drove or participated in all the activities in the organization, but most of the discipline engineers from engineering disciplines continuously changed. This gives strong focus on the conceptual design activity from system engineers but narrows the viewpoints in discussion. Further, this research case is from the governmental organization which does not develop the satellites in-house. It performs conceptual design and system design to develop RFPs to announce, and check the system designs proposed from manufacturers. More cases from industries will be recommended for the comprehensive research. Thus, this exploratory research intends to introduce the lessons learnt, but not the basic theory because of these limitations.

# *Chapter 4: Main Case Study*

This chapter documents and discusses a case from organization A. Currently, the organization A does not use ICE. Organization A tried to implement ICE concept and build a CDC for satellite concept design in it from 2002 to 2005, but the organization did not succeed. This chapter includes organization background, the situation organization A was in, implementation process the organization took, major steps and the reaction of the team members, tools the team used and how the implementation trial ended. These topics are observed from systems engineering and cultural viewpoints. Most of the data are acquired from the corporate database and some are from interviews of the team members involved to this trial in organization A.

Case overview is presented first (section 1) to capture the situation the organization A was in and whole stream of this case briefly. Each step the organization took follows with deep details in time series from start of the actions (section 2) to the ICE implementation activity stops (section 6). Then what the organization A is doing after giving up implementing an ICE is described (section 7).

## *4.1. Case overview*

The satellite system concept design team in the organization A works with classical Japanese style, which is presented in chapter 2. The design process, in-house engineering tools, knowledge, etc are often human dependent. Team members belong to different groups but ad-hoc meeting and informal meeting are frequently held. The responsibilities and roles of team members are flexible and even ambiguous sometimes. These characteristics make design team work flexibly and improve team performance. Intensive communication among the members, long time work experience and well established human relationships enable it.

However, human dependent work style forces team members to work harder and more intensively to improve the quality of design and to cut the schedule. It also heavily depends on the experience of the engineers. These issues are noticed by some managers and senior engineers who are responsible for the mission design and concept design. ICE design process and its great success were widely announced around year 2000 and recognized in the organization A, too. It looked like a great way to solve the issues the organization retains.

A group in the organization started to lead ICE implementation in it. The first step was taking consultation from an engineer, "the consultant" hereafter, who has great experiences in this field in the United States. The consultation contract included the demonstration of ICE process, consultation of how to develop the numerical model of parametric design and interfaces among disciplines. After the learning about ICE through consultation, the team stepped further to study and implement ICE by themselves. They built a small and partial prototype of CDC infrastructure and traced the design activity with a satellite concept which is already studied with the classical approach as an example. People recognized the merit of bringing tools and showing the analysis results over screen in discussion instead of bringing paper handouts. Then, they applied the ICE process to the subset of real satellite concept design, i.e. satellite orbit optimization to examine maximum performance of a mission sensor candidate. This let them know how the real-time analysis works while it was done in a small team. Some complaints and confusions are heard from the team members through these design activities but all of them basically worked well and the manager and team members admitted that the outputs with the ICE process are good and it will be efficient.

At that point, however, they found a huge gap to expand the process and infrastructure to meet the whole satellite system concept design. Engineers' understandings about ICE were insufficient. They decided to apply gradational transition from classical process to ICE process, but this did not work well. New IT infrastructure promoted discussion and information sharing but it did not change any basic behavior of team members or did not lead the shift from classical design approach to the ICE approach. On the contrary, the new tools and methods introduced successfully were of which fit to the classical approach.

Now, organization A is not using the ICE approach anymore. They stepped back to the classical design process, but they learned a lot through this failure especially from two different perspectives; systems engineering and culture. They are now restructuring the organization structure, developing design methods and processes more strategically not for the ICE implementation but for the original objectives by their own way; improving the quality of the concept design with less time.

## *4.2. Organization background*

The space industry is a very small market in Japan. Though some manufacturers develop satellites and launchers which have world class performance, the volume of sales is too small to assess if they have high quality and high reliability, and the high cost due to the low economy of scale decreases the international competitiveness. Thus, only 3 to 5 satellites are developed by the domestic manufacturers annually and almost all of them are ordered by the governmental organizations.

The organization A is one of the governmental organizations, which develops and operates satellites in Japan. It usually performs mission design and concept design in-house before officially starting as a project, then announces RFP to the manufacturers for design and development contracts. An integrated multi functional team is formed when a system concept design is requested from managers. The team includes system engineers, discipline engineers in the required engineering fields, operation engineers, mission instrument engineers and scientist, and so on. Sometimes people from promotion office, planning office or satellite project members in related missions also join the team. Most of the engineers belong to R&D department but any employees from other departments are assigned to the team as needed if available. The design team structure and relationship with organization structure just before starting an ICE implementation is shown in Figure 4-1.

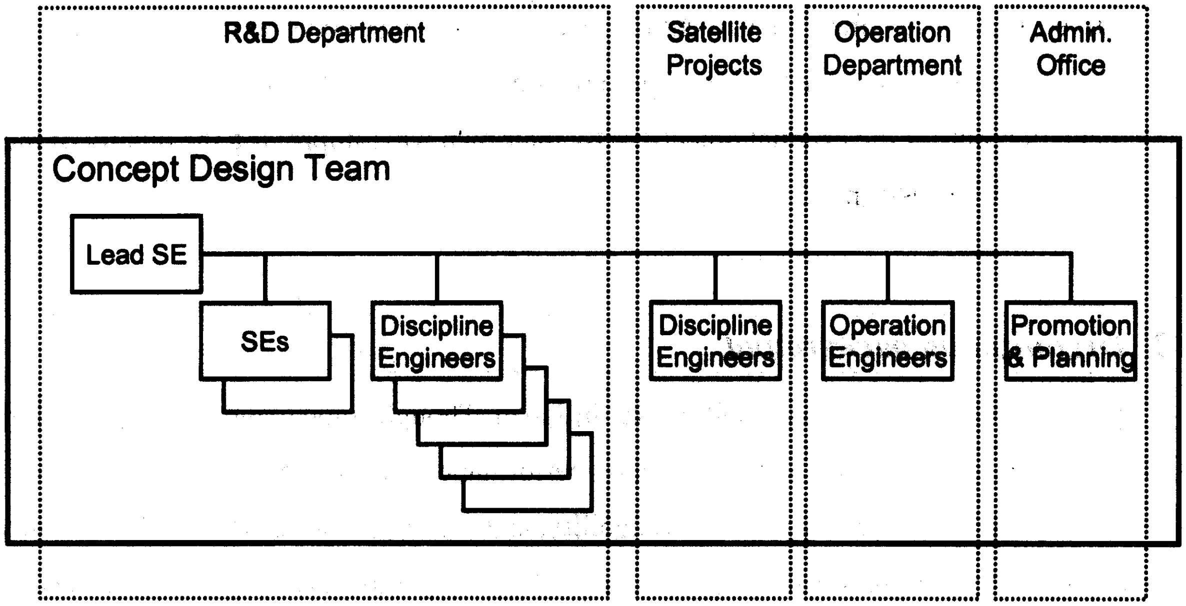

Figure 4- 1: The design team and organization structure

It usually took about 4 to 6 months to finish concept design, but it really depended on the missions. Some were finished in 3 months and others in 12 months. Many engineers thought it was rather long because the development time for the spacecrafts was being reduced in the other competing countries, and some thought they should propose small satellites frequently and quickly than the time and money consuming large satellites due to the tight budget. However, this long duration was not explicitly raised as an issue in the organization at that time. Three main reasons can explain this situation.

First, the in-house man power cost does not appeared in the design cost. This is very different in western organizations. The workweek is traditionally controlled and managed in total but not in task level in organization A as it has been observed often in Japanese organizations. This makes it very difficult to measure how much effort the team has made on what part of design activity. This means the workforce of engineers is considered as free resource as long as they accept the task assignment. Other resources used besides workforce during concept design are computers and software, whose costs are covered by the group each engineer belongs. They are not allocated to the design activities. Thus, the design cost does not increase even if the design activities stretched the periods. The long duration of a design study can be taken for their low productivity by their managers. But actually it affects their performance assessment only a little because their managers who evaluate them do not know precisely what they do for the design study and the relationship between long duration and their performance are not fairly measurable. As long as the engineers follow the design process and provide outputs for required task, they are not in the position to be blamed for that, and it is hard for the senior system engineer to report the long duration is due to the low performance of team members.

Second, lack of market competition reduces the importance of release timing. Profit is not the primary motivation that the governmental organization has by definition. It is heavily risk averse. Quality and reliability are of more importance than the schedule. Also the governmental budgeting policy strengthens this tendency. Once the project is admitted by the government, the project receives its budget annually and project is put under schedule and cost pressure. However, the organization resources, i.e. total budget and manpower are limited and there is little chance to highly increase the number of new project in short period even if a bunch of new good missions are proposed. Thus, as long as several numbers of new missions are proposed and adopted, the pressure to the mission design team is moderate.

Third, it is thought that satellite concept design inherently needs long duration. In general, it is usually very difficult to make a drastic change without continuous pressure for improvement. It is easier to work harder or overtime for instantaneous gain than creating new design process which needs relatively long time and let them own some risks to make things worse. People are conservative and do not feel comfortable to change their behavior especially if they experienced successes. Human dependent design process also makes it difficult for logical and drastic changes. Some engineers tried to improve the design capability occasionally and achieve some improvement, but the basic design process and behavior of team members stayed the same for a long time.

The design study was usually led by a senior system engineer (lead engineer), and a team works with “classical” approaches. Engineers performed their design or analysis tasks in their disciplines individually, and exchanged their results in the weekly meetings to set next tasks and due date. The design status was occasionally reported to senior managers and executive managers to redirect and adjust the design activity. The final outputs were also assessed by them to judge if the mission was worthwhile to budget and start as a project. The design process and procedures were highly dependent on the experience and preference of the team members, especially the lead system engineer. Each leader had his style. There was no organization standard process for the concept design or standard format for the design output, and the final report contents were different among the studies while some criteria existed for the phase milestones. Some showed strong leadership by proposing baseline design by themselves to drive the design and others would rather support team communication to encourage discipline engineers to collaborate with each other to drive the design by team. Some lead engineers preferred to put the first priority on the system performance, but others put it on reliability and operability. Some drove design into details until they feels it enough, but others finished when they came to the due date and left some details to the next phase.

These diversities in concept design activities sometimes reduced the quality of design, but some characteristics mitigated the potential issues and let the team run well without the standard processes.

- Intensive communication among teams helped to build the team
- All the tasks needed for concept designs were covered by experience without explicit standard documents
- Engineers knew well how each engineer worked due to the long relationship under the lifetime employment system
- It allowed some ambiguity in requirements and designs because they were continuously revised in the later phases as a characteristic of Japanese style concurrent engineering in chapter 2

Another interesting characteristic of the team was activity overlap among engineers as presented in chapter 2. System engineers organized satellite system design and they often designed and analyzed subsystems from system viewpoint, which could be responsible to the discipline engineers usually. For example, the system engineer performed orbit analysis and power budget analysis resulting to identify solar panel and battery requirements. In this case, electrical power and battery engineer examined detail of the subsystem and refined the results provided by the system engineer. Who did what kinds of analyses were decided by the capabilities and time availability of engineers. If both system engineer and discipline engineer had the same capability, they sometimes collaborated on one task. These overlap and circumstantial interface among engineers often worked well to maximize team capability and performance flexibility, but it made individual responsibility and information interface ambiguous.

One recognized issue was in the data management. At the end of the study, a thick final report was published as an output. It included the final design and its rationale, but it often did not include how the design candidates were created and selected or detailed conditions for analysis. Shared data server did not exist and all the data used or created for design were usually kept by engineers who created them. The data are shared person-to-person as request basis. Thus, the data were vaporized as time goes on and it was difficult to collect data created in 10 years ago or the before.

Under this circumstance, a senior engineer in the organization A had a chance to talk to an engineer who had successfully run a CDC and performed a number of satellite system concept designs in the United States. The senior engineer found there were four main reasons to implement ICE concept in the organization A.

- To improve satellite design quality for the better concept and system architecture
- To reduce design period drastically
- To create and maintain unified shared database for concept design studies
- To increase the design capabilities of engineers through design experience, storing and sharing the knowledge and data

In 2002, the manager and the consultant agreed to sign the contract for consultation to introduce (not implement) ICE to the organization A and train engineers to help them be familiar with ICE. Actually the manager was not responsible for concept design but responsible for infrastructure development to support engineering activities. Let me call the group as "IT support group" in this case study. This trial was started by the IT support group and discipline engineers helped it. Only 3 engineers were assigned to this activity in the group at the beginning and the contribution from other groups were essential. System engineers joined the activity right after the consultation started. The relationships of these groups are shown in Figure 4-2 below.

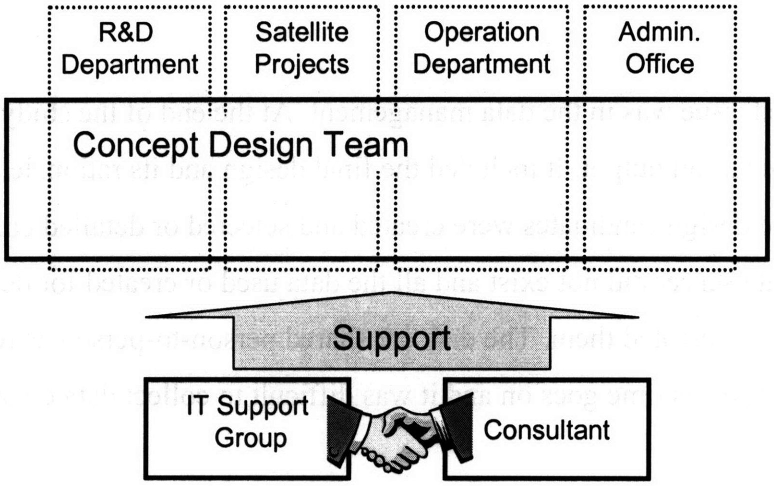

Figure 4- 2: Stakeholders for ICE consultation

## 4.3. *Consultation to implement ICE process and environment*

The consultation contract consisted of two parts. The first part included demonstrating how the real-time parametric design goes on under the ICE concept. It was executed by developing a small ICE environment and system models, training the engineers and running a design session. It used a satellite system which was already launched as an example. The second part included identifying and visualizing the design parameters for engineering disciplines. Intensive interviews were conducted with the discipline engineers. It used a satellite system which was under concept design with classical approach as an example. This consultation was performed in 2002.

### 4.3.1. *First step: A Real-time Parametric Design Demonstration*

The first step of the consultation was demonstrating how the real-time parametric design would be operated in the ICE concept. This was thought to be the key part which delivered the main value of the ICE concept though there were some other essential parts to know how the ICE works. How and what tools and environments were used in the CDCs were the greatest interest of the organization A at the starting point.

Variety of tools and their combinations were actually chosen for the ICE environments. High-end COTS tools and spreadsheets were the most typical tools used but some organizations used only spreadsheets and others used both high-end COTS tools and spreadsheets. They often developed their own tools and flexibly combined these tools to fit their design teams and objectives. In this case, the consultant has had much experiences and deep knowledge in ICE using high-end COTS tools. The senior engineer who was responsible for this contract discussed with the consultant and offered to his opinion;

- Detailed analysis at the early design stage with high-end tools can create the reliable and high quality system design
- Reliable and high quality system design helps to define the highly feasible and low risk system concept

The organization A has continuously developed technically challenging satellites in its history because of its role in the government. Also, the consultant's opinion was supported by the fact that some leading organizations used high-end tools for ICE in the United States and Europe. Thus, the IT support group decided to follow the suggestion of the consultant to use the high-end tools. Discipline engineers was a little bit skeptical if they could use them but agreed to try it. The design team for the demonstration was formed with system management, satellite geometry, two engineering disciplines and the design session leader. System management kept track on all the key parameters of the satellite and its geometry provided as 3D physical model. The satellite system example was chosen from the satellites that the organization developed and the discipline engineers had some experience in its development. The design infrastructure was developed by the IT support group with the existing equipment.

After all the engineers developed the simple models of the satellite in their domain and confirmed the interface, a design session was conducted. Geometry for some components was changed to improve the performance of the satellite, e.g. solar panel size, antenna dish size, etc.

Discipline A and B received the changes and ran the simulations to figure out the effects of the changes. System management tracked all the parameter sets including the outputs from the disciplines. The data flow is shown in figure 4-3 and please note that all the parameters were collected by system management while it was not presented in the figure. Discipline B received the geometrical changes automatically by receiving 3D CAD data in standard format but discipline A reflected the changes manually because of data incompatibility problem. The design cycle time was about 10 to 15 minutes and the session finished in about 90 minutes after roughly optimizing the system configuration and understanding how the real-time parametric design worked.

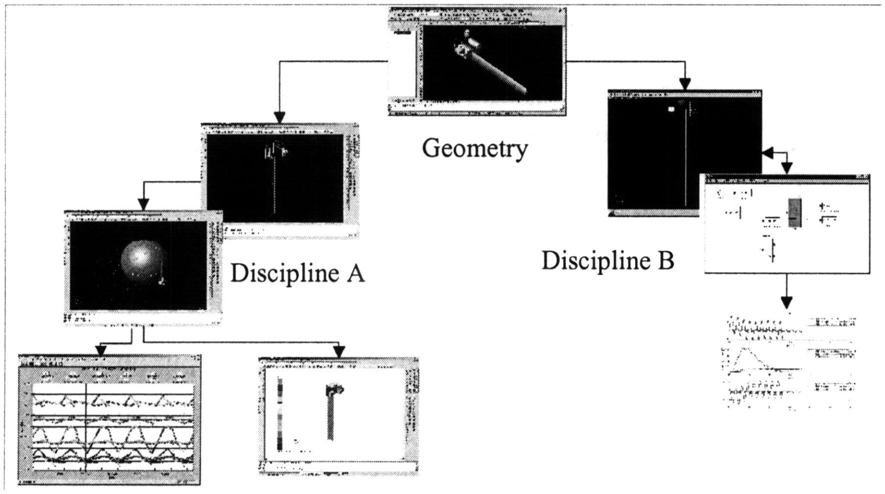

Figure 4- 3: Parameter Design Flow

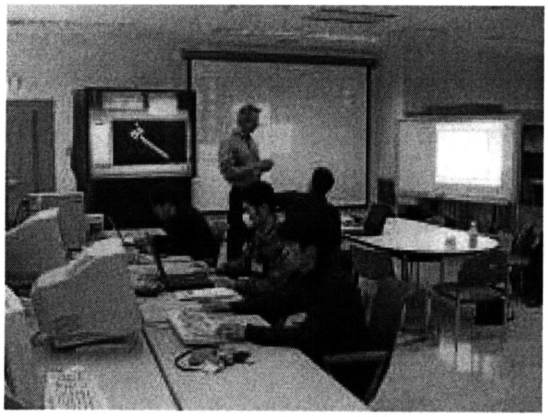

Figure 4- 4: Real-time Parametric Design Demonstration in Progress

All the participants understand and recognized these two points as the main takeaways from this session;

- how the real-time parametric design worked, and
- team design performance improvement with holistic view was possible

At the same time, some participants pointed out several problems in the real-time parametric design as below. They mainly came from the confusion about the drastic process changes and the difference of the situation between the demonstration and the real design activities.

*"This demonstration worked well and smoothly just because it was I think so simple as the data flows only one way and the changes were limited. In the real world, the data flows are mutual and so many interfaces exist."*

*"I don't like to be asked the design changes and analysis with strong time pressure. The more the model is complex, the more the details and analysis condition have to be taken care of. I am afraid that the quick analysis brings more bugs in our models."*

*"In the real system design, the interfaces are usually very complicated. Every input parameter can be turned out to be output for the different analysis. It is not so simple like this demonstration.*

*"The parameter changes were so simple in this demonstration but usually it requires changing not only the size of component but also its positions or sometimes the model itself. Redesigning the model can take more than one hour!"*

*"I often asked detailed analysis to judge the feasibility of the target performance and it sometimes takes a couple of days to run the simulations. Real-time design will not be applicable."*

The next question is how to expand the success of simple and small part of a system design to a whole system design which is complex, with everything changing dynamically through the design activity.

### *4.3.2. Second step: Interface Identification*

The organization A has had the criteria for the concept design phase but it left some ambiguity in it. While it was reasonable that some critical subsystems needed deep analysis to assure the feasibility, there was no clear definition of the criteria. Lead engineer and other stakeholders requested the outputs they wanted from the discipline engineers, and discipline engineers also negotiated with the leader for the appropriate design goals based on their capability and time availability. Sometimes they were requested to execute extra analysis by the team leader or people in promotion group, which might be only needed in the next phase because some stakeholders think "the more, the better" and the ambiguities in the criteria allowed asking that of them. The design team leader or managers decided if they did enough to finish the study using their experiences.

Discipline engineers identified the analysis to perform, its depth and the data interface among the discipline engineers in every design study. Actually, some engineers have had their standard analysis tasks and outputs for the concept study. It varied among the engineers even in the same discipline, and the interfaces to the other disciplines had to be identified every time because the interfaces were changed when the other discipline engineers were different. Thus, the IT support group recognized it was very difficult to identify the standard input and output interfaces for the concept design.

The IT support group and the consultant selected a satellite system which was under concept design study with the classical approach. This might lose some commonality of the system model but it would enable engineers to easily identify the inputs and outputs of the concept design study. Interviews were performed intensively and they talked to 8 discipline engineers and 2 system engineers including lead system engineer. The objectives of the interview were to identify the design process, subsystem models, the tools engineers use, and data inputs and outputs for each discipline.

Through the interviews, they developed several chart to visualize and organize the data flows. The data flow block diagram for each discipline captured the elemental information needed. It included the main tasks of the discipline, the inputs from the other disciplines, and the outputs to others and the tools they used. The basic format is shown in Figure 4-5. All the information from all the disciplines was aggregated into a chart to map the whole system data interface. This chart is shown in Figure 4-6. Please note that the original data in these charts touches on the corporate secrets and anonymous symbols are used.

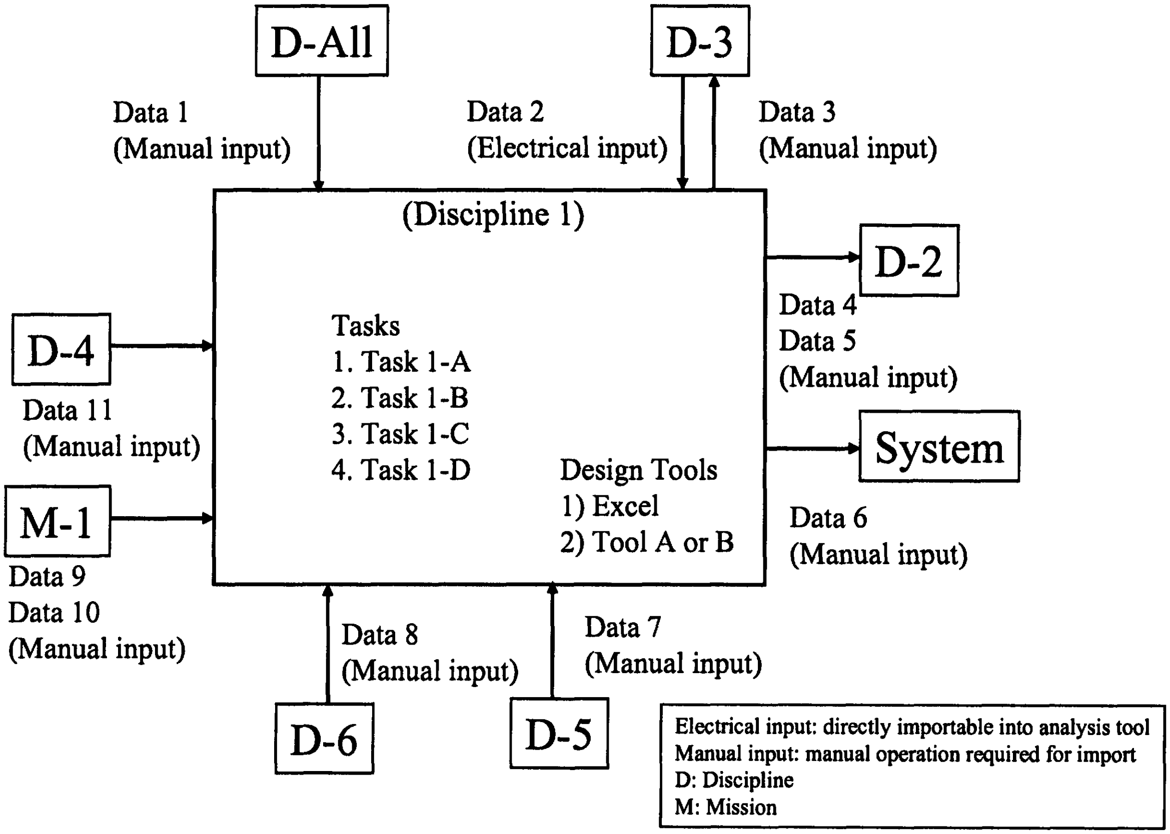

Figure 4- 5: Data Flow Block Diagram

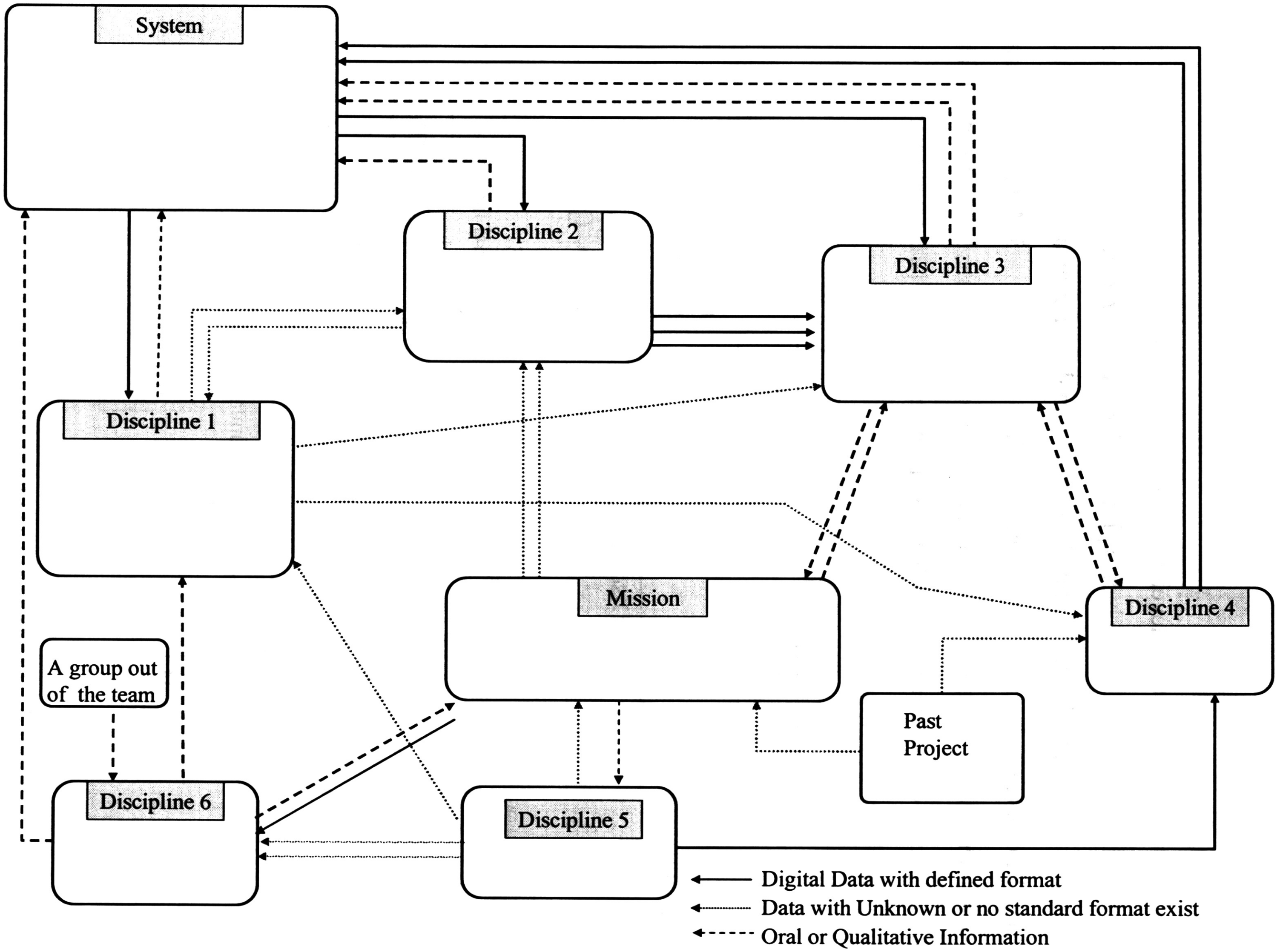

Figure 4- 6: System Data Flow Map

Analyzing the results of the interviews revealed several interesting characteristics of the data flow and tool usage as below.

- **Data were exchanged over documents and many "format not defined" data interfaces were found.**

Most of the data were exchanged over the documents or orally in the meetings while these data were created through the analysis tools. The biggest reason was the engineers in different disciplines used different format for the same data. They were basically good at handling stand alone tools or spreadsheet but not so good at coding with programming languages for the data conversion. Some engineers also limited their analysis to some critical case or worst case instead of analyzing all the timelines or data points. This allowed them operate the data manually.

The same information was able to be expressed with different ways. For instance, the orbit was expressed with six elements but the different combination of the elements or different frame of references were able to be used. The engineers sometimes sent and received the same data with different format and interpret the data in each study. This is why the engineers believed the data format is not defined. They established the data interface as needed flexibly.

- **Some disciplines created the same data respectively.**

This is because of the lack of the communication among the disciplines and difference of the data format for the tools they use. For example, both thermal analysis on orbit and structure analysis at launch needed satellite 3D CAD models. They collected the geometry information from system engineers who built the basic physical architecture of the satellite by drawings or hand sketches. Even if the CAD data were available, they could not be converted to the format completely which the discipline engineers' tools can handle. They also did not like to track the changes of models because they thought the frequent check in and check out of the models and re-convert the data at every changes increased the work overhead.

- **Some engineers executed the analysis needed with simple tools, and they spent a long time for cumbersome and time consuming manual operation.**

As mentioned above, most of the engineers were not so good at coding the program they wanted and used COTS tools with GUI or simple spreadsheets. COTS tools were often powerful but not much flexible and the GUI interfaces required time for handling the model or executing the analysis. Spreadsheets were preferred by some engineers because they were cheap, flexible and available in almost all the computers while it was not good for optimization or the complex parametric studies. The engineers iteratively changed parameters to find the optimal design manually. It took a lot of time to find the answer and check if it was not just a local optimum.

All of them wanted the automatic tools to execute their analysis handy and quickly but they also wanted high flexibility than ease of use. This was the big dilemma to the IT support group and the consultant. They could develop handy tools for the discipline engineers but it was almost impossible to keep on updating them to meet all the requests from the discipline engineers continuously.

To improve this situation by leveraging IT infrastructure, several high-end COTS tools were suggested from the consultant. Data transfer techniques among the tools were also suggested based on his experiences. However, several issues came up when they tried to use them. First, these tools suggested were new to most of the engineers. Learning high-end COTS tools sometimes took quite a few hours to handle the tools quickly and to wield them. The discipline engineers had a lot of other job assignments and could not spend such a long time to learn them only for the CDC. The experienced system engineers commented;

*"I think we do not need to stick at the high-end tools for design and analyses. If we can use calculator, why not use the simplest and easiest tools?"*

*"High-end COTS tools actually have varieties of functions but some in-house tools are always required. There are some analyses which are unique to the mission, usually."*

*"Is it so important to define the interface and data flow among the tools? The critical points which require deep analyses and the tools to use will change according to the mission and architecture of the satellite. I worry about that the inflexible toolset may make the total design activity inflexible."*

Second, the data conversion did not work perfectly as expected. 3D CAD data was required to use other graphic tool to create intermediate format to pass it to thermal analysis tool. Further, the converted data could not be modified freely. Every major correction and modification to the 3D model had to be made with the CAD software. These obstacles were too big to overcome in short term. They got back to the starting point about tool integration for CDC.

Third, they were skeptical if the ICE could reduce the team members' workload because they were required new tasks which were not recommended in the classical design process. The availability of engineers also could be a problem. Some discipline engineers and system engineers commented as;

*"In-house tools and data interface should be maintained as needed for the design sessions in each study. Who maintain them? The engineer who use it will heavily involved in it because it is he who knows what is required for the tool. However, they are too busy to retain new work."*

*"The concurrent design (ICE) seems like not the method which reduces our work. Improving the quality of design always requires higher workload to the team members."*

*"While mission design and concept design study is recognized of its importance, the human resource will not be improved (in the coming several years). I doubt if it will be our solution to follow other organizations (which have much more human resources than us) are doing."*

This consultation itself was done correctly and better than expected. The concept design team learned a lot about how the real-time design in ICE concept works, but they found some big obstacles to overcome to implement an ICE concept into the concept design study. The task assignments were too ambiguous to define the tools and interfaces rigidly, and the discipline engineers were not able to modify and adjust the tools quickly to fit the flexible task and interface identification in each study. Above all, most of the team members thought that they would gain something good from ICE but it should be modified to fit their culture and situation which was obviously different with other organizations in the western countries.

### *4.4. Mission analysis demonstration*

Considering the result of consultation, it was almost impossible to identify the standard tasks, tools and interfaces in the concept design study as the basis of an ICE implementation. They found that it would be better to build the environment and system analyses models and interface models from scratch than modifying the current tools or infrastructures. They started this activity right after the consultation finished; from the end in year 2002. The main objectives of this study were to check if the design team could run the CDC and recognize its advantages and disadvantages by demonstrating the parametric design with ICE. The new design team and infrastructure were built with the characteristics as follows.

- A team is small enough to be control easily.
- The satellite system to study selected is the one that the team is familiar with and already designed.
- The team members can develop or modify by themselves to fit the design objectives.
- All the analysis are well defined with clear inputs and outputs

Actually, the satellite chosen for this study was that used in the consultation, which had just finished its concept design with classical approach. This satellite had 2 different full time main missions, and their compatibility and operability were the key factors for the system feasibility. The team was composed of 7 engineers; 3 engineers for mission, 2 for disciplines, and 2 for system. They developed the system model which consisted of key functions and subsystems. Tasks and data interfaces were also clarified for clear task flow and clear data interface. Data exchange was not fully automated to avoid the complexity of the tools, but system engineer understand who created what data and information could be controlled well. After setting up the network, tools and data share server, an information session was held to understand how the design session would be proceeded. It was planned as a mission design with real-time analysis and team discussion.

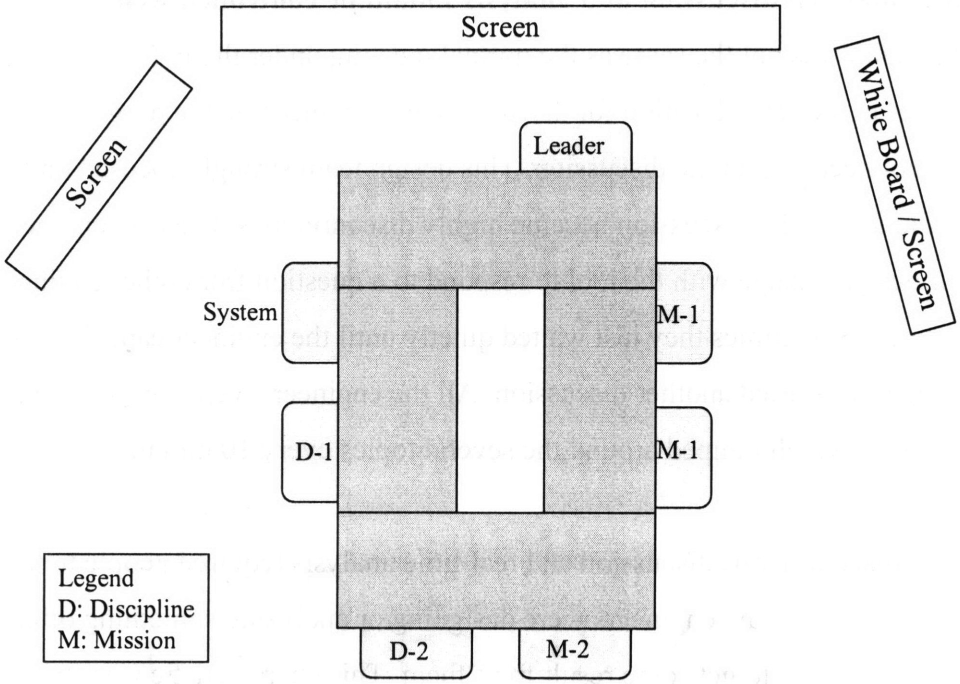

Figure 4- 7: Mission Design Demonstration Facility Layouts

Figure 4- 8: Mission Design Demonstration in Progress

The real-time design session continued about 3 hours and several design cycles were performed. While it was a short and small design session, they got a lot of new findings as follows.

- **Balance between discussion and analysis should be controlled well**

A design session was not the same as the normal meeting under the ICE concept. The design team got together in the same location for discussion and engineers made progress in their tasks when they did not need to join the discussion. This design team strongly focused on the former part and they found that the discussion became highly discontinuous. Once an engineer started his analysis or design change with the tool to respond to a question from other engineer, the discussion stopped. Sometimes they just waited quietly until the engineer came back with the answer, or sometimes started another discussion. All the engineers were confused to follow or lead the discussions which jumped around the several topics every 10 minutes or so.

Besides, the discontinuous discussion and real-time analysis required people to think and act in quick cycle. When you saw engineers were designing or analyzing something often meant that someone was waiting to get some result from them. This characteristic was strengthened in this demonstration because they focused on team discussion. Even the organizations which implemented the original ICE concept, Coffee (2006) reported that "People are forced to work smarter and quicker." Given this was a big merit of the ICE concept, this could work negatively too. An engineer commented that "This approach does not allow us to think things over and over for the better answer and leads us to report the first feasible answer without checking if it is a local optimal."

- **Bringing in analysis tools leads to deep and further discussion**

While the team members got confused how to manage the team discussion and individual analysis at the same time, bringing tools into discussion gave a big merit to the team with surprise. When any team member came up to a question for the result of someone's analysis, the engineer could start to explain the logic and the condition of analysis. In the classical approach, not all the logic or conditions were documented, and the discussion could not hit the details. Now, everyone could show and explain everything he did. This sometimes helped to find engineers had different assumptions and conditions, which were followed by re-examining the system model, system concept, and even the system requirements. This was not expected by the team before starting the session.

- **Huge amount of data is created in quick design cycle to be managed well**

The quick design cycle enabled the team to examine many cases by running tools with variety of parameter settings. At least 3 to 5 parameter settings were examined in a discipline to go through a design cycle. At the end of the session, every discipline created 10 to 20 set of design and analysis in total. Not only the final design, but also the other down-selected cases were also important to be documented to understand why the final design was selected and why other designs did not work well. In the classical design approach, each engineer executed their analysis or created the design after thinking it over and created much fewer number of design candidates to show. Even high volume of candidates were created, they could manage them during the long interval between the meetings.

ICE encouraged quick analysis and design cycle but it made manual data management almost impossible at the same time. All the engineers joined the session agreed with this point and recommended automatic data management system which will label and sort all the data and figures created. If possible, automatic documentation system which would convert the document and data into the report format helps them a lot.

Additionally, the lead engineer pointed out the importance of documentation during the session. The design team had assigned a person for documentation but the expected duty and performance was not so high in the classical design studies because all the participants with any issues or reports prepared some document to show. Discussion was often made based on the document and there were some continuous flow of the discussion to follow. The only exception was brain storming. With the ICE approach, the discussions were often discontinuous and many interruptions occurred as engineers work on design and analysis tools. The importance of documentation was highly increased to organized the result of discussions.

- **Limitation of tools; non-reversible data flow and non-all-purpose**

As the tools were not developed to be able to switch input to output, the discussion was not as free as that was with the classical approach. The design task flow was semi-formally defined and just went back to the former task to reset the design based on the result of certain tasks. For example, as shown in Figure 4-9, the output from "discipline 1" was passed to "mission 1" as its input, and then the output of "mission 1" was passed to "discipline 2" as its input. Sometimes they wanted to run this flow of analyses reverse way to see the impact on the input parameter for discipline 1 by changing the output of discipline 2.

Figure 4- 9: Non-reversible Data Flow Among the Tools

In the classical process, this reverse flow could be done during the one week interval just if needed, but they found the real-time analysis required tools be ready to do that. Of course, no tools could do all the analyses the engineers wanted but in-house-tools were developed to fit some variety of analyses and developers wanted to limit to the minimum capability to save their efforts. Even if they did not implement some capability into the tools, the software should be coded to be able to expand the capability easily. Not to mention, "Hard coding" should be avoided but it required substantial experience to implement modularity and flexibility into the software architecture for expansion in the future. It was almost impossible to expect that coding capability in the engineers or even software general programmers. Then, the questions were "For what purpose are the design and analysis software used, specifically?" or "What kind of problems were supposed to be solved by real-time analysis?"

## *4.5. Success in simple Mission Feasibility Analysis*

In the second quarter of 2003, a small System Design (SD) group was established in IT support group to reinforce the ICE implementation activity. The size was still small and 4 engineers are assigned. The concept design team structure was as in Figure 4-10. Their main responsibilities were leading concept design study, system design study, trying an ICE implementation in it. As they were a part of IT support group, they were requested to mainly focus on developing IT infrastructure which was one of the key elements of the ICE concept. The group was constituted by a lead engineer and several system engineers and most of them were the team members for the ICE demonstrations.

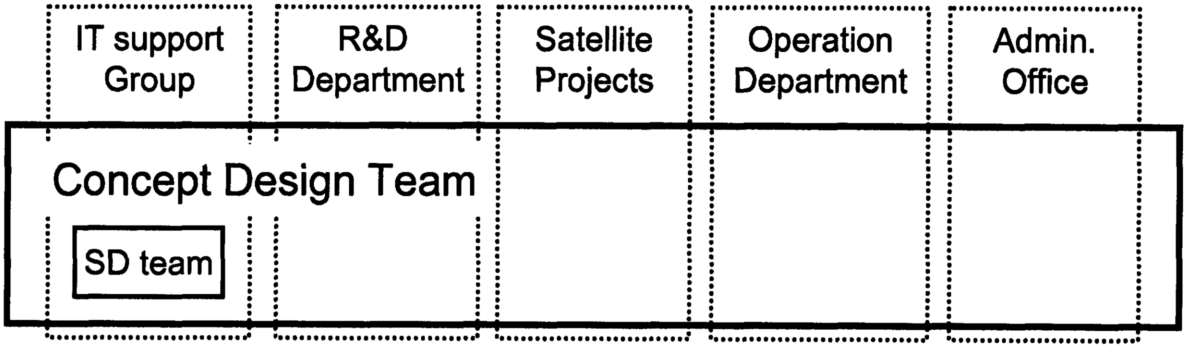

Figure 4- 10: Concept Design Team Structure

Right after the group established, they came across a good opportunity to try the ICE concept for a real mission. The “mission A” is already admitted to start as a project before the concept design because of its scientific and political significance. Pre-project team was formed and they were performing the satellite concept design within their team resource. However, they asked the IT support group to help the feasibility study for a mission sensor. The mission sensor technology and its method how the sensor works were totally new, and no satellite mounted that sensor before. There was no data or public report about it in the world. Therefore, it was required to figure out its performance, advantages, limitations and constraints to decide this sensor was worth to mount on the satellite than the other sensor candidates.

Considering the lessons and learnt form the past activities, this study seemed to fit well for ICE concept to apply because;

- the objectives and mission of the satellite system were already clear
- the study area was limited to examine the feasibility of the sensor and the design team will be very small

- it required quantitative analysis
- the members of SD group had coding capability to build tools
- some project members including the project manager had worked with the lead engineer in the past and know their personalities each other
- the pre-project team, especially the manager, was interested in the ICE concept and apply it to the study

The SD group members could develop the analysis tools and infrastructure from the scratch for the study. It gave the complete design toolset with clear and smooth interfaces. The design procedures were simple since the target system was small and design area was limited. Small team allowed intensive communication and quick reflection of team decision to design process, tools and infrastructure. Even though the system and process developed and used in this study were not applicable to the other concept design study without at least some modifications, they could examine how the real-time design session worked for the real mission with the real customers. They also could receive customer feedback to the study. The team was formed by a lead engineer, two system engineers and pre-project members as customers. No discipline engineers from R&D department were involved.

The team started to work from sharing information about the mission, the sensor and how it would work. Then, they defined the objectives of study, tasks to do, schedule and expected outputs in the kick-off meeting. SD group developed a prototype of the design toolset and the output image formats in the next meeting, which was held a week later, to confirm if they captured their requirements correctly.

This three-hour-meeting also worked like a concurrent design session for tool development. The team members discussed about tools' functions, user interfaces, visual format for the outputs, and output data and analysis conditions in details. Lead engineer and system engineers explained about what the tools could do and how they work through operating them step by step. They were asked about the analysis conditions and parameter settings and system engineers answered quickly since all the data and tools were in their hands. They changed the parameter settings right after the customer requested during the meeting. They also changed the graphs and data formats as the customer wanted. Sometimes the system engineers challenged to the customer's requests how large impact the requests would give to the analysis time or accuracy of outputs. It was done by changing the code and showing part of the analysis results to the customers. They came to the basic agreement about what analysis would be done and how long it would take. The team had a good start.

They developed the whole analysis tools and defined the analysis flows in the next 2 weeks. The analysis flow was shown in Figure 4-11. The flow was quite simple and straight forward. The tools for analysis A, D, E and F were developed by a system engineer with three COTS software packages, and the lead engineer developed the tools for analysis B and C with programming language C++ and Ruby. The tools could be integrated into one tool if they developed all the tools with the programming languages, but it would give less flexible operation capability to the team. COTS tools also have powerful analysis engine, higher graphic capability and convenient coding and debugging environment for quick programming than the typical programming languages. Above all, diverged analysis environment will be good for ICE environment simulation. All the data files were planed to be shared through the data server and stored in it.

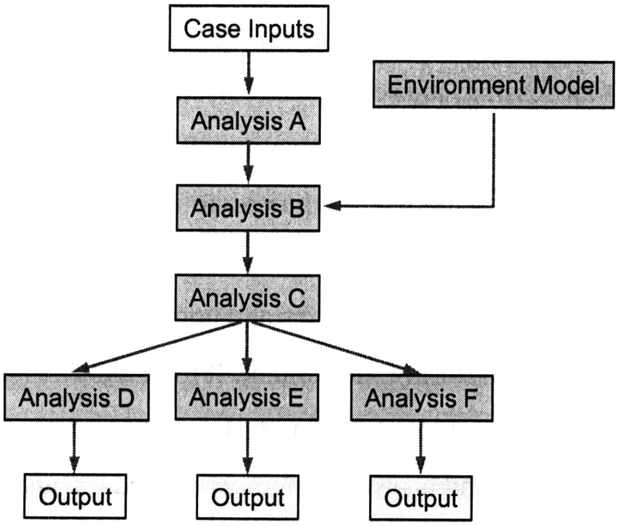

Figure 4- 11: Analysis Flow for the Mission Sensor Feasibility Study

### Concurrent Analysis Session 1

The lead engineer and the system engineers performed pre-required analyses from the customers before the first real-time design session to save time for discussion. Though several cases were analyzed before the session, most of the time in the first session was spent for a case which was thought as the most typical case of this satellite mission category. As it was mentioned above, this sensor and its operation method had never been on board. This was actually the first trial of how it worked on satellite so far as the team members know. The team tried to understand how this was made and what did the created graphic patterns represent. The lead engineer and system engineers explained the data from various different viewpoints, e.g. in time series and statistics, in real-time operation. They also created animations to explain the simulation results. Customers had high engineering capability and they could have intensive discussion even without the ICE, but these tools and the discussion environment obviously helped them understand the result of the case analysis quickly compared to explaining them with paper handouts and drawings on the white board. Running simulations with different parameter settings pushed their discussion forward without waiting for the next meeting. The team identified which cases should be analyzed more in the next step and the 3-hour-long first concurrent analysis session finished successfully.

### Concurrent Analysis Session 2

After 10 days from the first session, the second concurrent analysis session was held. The team already completed modifying the tools and executing all the cases requested in advance. In the session, the team worked similar to the way in the previous session but much more smoothly. They discussed the analysis results and tried to analyze several cases with other parameter settings to find the sensor's optimal usage, limitations and constraints in use. It continued about 3 hours and about 5 analyses were run during the session. It took about 15 minutes to run through an analysis cycle and each step took 2-3 minutes to run. The discussion stopped all the time when an analysis was requested and a system engineer started the analysis, but the lead engineer successfully managed to restart the discussion in most cases without waiting for the analyses to be done because the topic area was so limited that they could jump on the different case or topic, and they could come back the point they left easily when the analysis was done.

The merit of concurrent session was not only in the analysis but also in data visualization. Since many cases were analyzed in this study, they tiled the results on the large screen to compare the results from different cases. Changing the tiling combination, each location or graph size on screen helped to understand the difference among the graphs correctly, effectively and quickly. Flexibility in visualization enhanced their discussion a lot without doubt. This could not be achieved in the classical meetings and all the team members including the customers were satisfied with that the mini CDC provided.

**Off-line post processing**

It took just two concurrent analysis sessions to finish the feasibility analysis of the mission sensor in success. Then, a few tasks were left to complete the study. Customers selected eleven analysis cases and 85 graphs and their numerical data were provided after the sessions. After that, the customer brought more accurate environmental model and requested re-run the analysis with it and with smaller time step. They also requested to perform the same analysis for a different orbit. While only a few cases created most of the value in this study, the customer wanted all the cases to prove they examined the broad area thoroughly. It made the system engineers busy because some tools are based on COTS tools and required GUI operation. They were not automated or not able to batch all the tasks. This problem was recognized in the ICE demonstration last year, too. It was trade offs between (1) development cost and operation cost, (2) flexible interface and solid standard interface, and (3) extendibility in functionality and fixed but pre-set high functionality.

As the final step, the team held the wrap up meeting after final report was written up. Basically all the team members were satisfied with the results, time they spent, the process, tools and infrastructure they used. The customer representative, namely the project manager, pointed out that the key reasons of this success were;

- The mission and input conditions for this study were clearly defined at the beginning of this study.
- Analyses were relatively simple and engineers are well trained for tool handling.

- Tools to compensate COTS were developed quickly and worked well.
- Enormous data were created but they were well visualized for review and discussion.
- In short, well established infrastructure and talented engineers were the keys for success.

While the manager liked the ICE concept used in this study, his opinion on if this can be expanded to the satellite concept design study was negative because it would be difficult for a large design team to fulfill all the key points above when he considered the current corporate situations and characteristics of satellite system. The biggest concern were reserving the sufficient number of the discipline engineers and reserving their time to coordinate the session and develop the tools for the sessions.

This meeting was closed with the team recommendations as follows.

- Multiple screens are desirable even for the simple analyses session like this study.
- Automated data processing tools for final report are required to handle substantial amount of outputs.
- Some action should be taken to reduce the noise from the projectors and PCs in the room.
- The leaders need operation capability which enables to keep members' motivation high enough through the long session.

## *4.6. Implementation Barriers to Concept Design Study*

The mission sensor feasibility study proved that the ICE concept could work when it was operated by a small team for a small system as a minimum set in the organization A. The next step should be making a plan, how to expand the scale of the design toolset and how to let the team members transit from the classical process to the ICE process. Since SD group had tightly limited resources, it was almost impossible to develop a full ICE toolset and jump on it discontinuously. It was also almost impossible to educate all the discipline engineers quickly to cover all the capabilities to work under the ICE process which was demonstrated in the previous studies. They should had enough capability to design the whole subsystem with system viewpoint. They should be able to handle the design tools quickly and flexibly for the real-time parametric design (and coding capability if possible). They should be able to define the interface with the disciplines which have input/output interface. It would take quite some time to get them ready to work smoothly under the ICE process even only for the key engineers. Above all, all the discipline engineers were very busy and managed by the leaders of discipline engineering groups. It was easy to guess that they will face some problems to find a time for their trainings for ICE trial which their bosses were not responsible for. Therefore, they decided to take the gradational implementation strategy.

The SD group continued the research and development for flexible toolset and better design infrastructure by themselves, but the actual changes they brought into the concept design activity as the first step were not large.

First, they equipped computers in the design room and encouraged team members to bring their analysis tools to enhance the team discussion. Sometimes SD team installed and set up the tools in the computers in the room. Even if the engineers could not run the real-time analysis in the sessions, only showing the results could help the discussion than that without it. This was thought to give some merit to the discipline engineers, too because they did not need to prepare hands outs with full of graphs and figures. They just could run the simulation and explain the results orally. Then, they could document them quickly if needed.

Second, they set up a Linux file server for integrated data management. They defined the folder structure and the rule of its use, then announced it every time to the team when they form the team. Formerly, they had been stored and managed only as handouts provided in the meetings and the thick final reports. Every team member could access only to these printed documents and all the electronic data, analysis data, etc. were kept by the engineers who created them.

Third, they encouraged discipline engineers to provide a prospective subsystem model even if it was primitive one. Discipline engineers tended to not provide their design until the subsystem requirements were clearly defined. They were willing to discuss about constraints and feasibility about their subsystem but often passively waited to receive requirements for them in the system design. It was more like a centralized design team. Lead engineer and system engineers were the hub of the team. However, the main stream in an ICE was distributed design team. It was based on the intensive discussion and information exchange among the discipline engineers. The SD team tried to pull them up to the same level with them for the system design discussions.

The result was not as desirable as they expected. Shortage of human resource was the major miss in estimation. They faced increasing demand for mission design and mission analysis studies, and large portion of their team resources are allocated to them. Some studies had a tight schedule. They did not have time to develop the tools and train engineers. Other missions were too early to design the satellite system configuration because even the observation methods for missions were not established. There were a few studies in which they tried to implement the three changes but the degree or improvement was limited. They observed some changes and persistency in tool and infrastructure usages, team members' behavior and process.

### Tools and Infrastructure Usage

Analysis tools were increasingly used in the design activities. When it was applicable, some discipline engineers brought design tools but only to show the design and analysis results. The main reasons were that the tools were not flexible and well coded for quick analysis, and they did not make any change in tools to fit it. The system configuration changes often in the early stage of the mission design phase. They usually made very rough calculation with a calculator or answered just based on the engineers' experience instead of running the tools when they asked some changes during the meeting. Even if they could run the tools, it sometimes took 10 to 20 minutes to complete a simulation or to handle the complex GUI. Most of the engineers did not try new tools. They just used tools which they were familiar with. Standard tasks or interfaces were not able to identify because the collaborative analysis or design among discipline engineers did not happen. The only thing all the members eagerly used was the file server. It was widely supported that they could search and get any data even during the team discussion.

Automated documentation system was not built because when they tried to build a prototype, the engine of the tool could not handle the 2 bite characters well. They could not find a solution for the encoding and format styling problems.

### Team Members' Behavior and Process

While the lead engineer encouraged discipline engineers to set a design baseline and improve it continuously from the early stage of concept design study, they hesitated to provide unsatisfactory design or were confused to be asked to design without defined requirements. Actually most of the discipline engineers were confused how they should react to the changes and even after they understood how the changes work, how they could work to achieve the goal was open question. Making things worse, the different discipline engineers were assigned to the different studies and they could not gain experiences enough as a team.

One custom the discipline engineers could not adapt was the change from "presentation and questions" style to "open discussion" style. In the classical design study, the team meeting went with presentations where engineers explain what they did and what they would do next. Question and discussion time was set in several minutes after the presentation. However, they could ask any question any time in the open discussion. They were not eager to ask questions or comment when a few people are discussing or presenting something in a large group; 15 to 25 people in total. When they held a small group meeting for the special issues, like data communication or satellite operation with 4 to 6 people, the discussion was much more active than the team meeting. It would require some cultural change to make the open discussion work.

Finally, after two years more trial little by little, they stopped the gradational ICE implementation. Even though they achieved good outputs for the mission design study and concept design study, it was obvious that they were not close enough to the goal to implement an ICE concept. They found they needed some other basic changes before trying to implement an ICE in their team.

## *4.7. After the Failure*

There was a trigger which made them decide to stop and reset their ICE implementation trials. Right before they stopped it, a new activity on systems engineering was started by a new task force outside of the team as a coincidence. They were totally independent of each other. The main objective of the new task force was to launch a program to reconstruct and renew the system engineering standard for the better and effective system development in the entire organization. It was not so common but the activity started with top-down approach; not like the bottom-up ICE implementation trials. The SD group were assigned to join it, and started to review the design process, expected tasks and outputs, and responsibilities of team members for the concept design. Of course, improving design tools and methods was still in their focus. Tools and methods obviously helped them a lot if they were used as well fitted to their activities. They focused more on the design process, tasks and inputs/outputs to re-design the concept design activity.

They don't use the ICE now, but it may have another chance to be implemented after the process and team is identified explicitly. It may take some time to be ready for smooth implementation of ICE, though.

# *Chapter 5: Reference Case Studies*

The reference cases are included in this chapter to compare with the main case described in the previous chapter. It usually widely varies why organizations fail to do something. On the contrary, it is also often the case that organizations have success in something for some common reasons. The key features for the ICE and its implementation are already documented briefly in the chapter 2, but the circumstances and procedures, how and why some organizations have succeeded to implement the ICE are focused on and discussed in this chapter.

The first things to be mentioned are the situation they were in, the motivation to implement the ICE in it, and the strategy they chose. It is followed by how the management support was important. Then, what they focused on and how they implemented the key features of the ICE, i.e. the team, the design process, the system models, the design and analysis tools, and the infrastructure. Please note that the cases described in this chapter are cited from the literatures due to the difficulties to access the corporate data. The two main cases succeeded in implementing the ICE chosen for this study are the anonymous private company, let me call it as company B hereafter, case report by Stagney (2003) and the Satellite design office (SDO) in the Astrium/EADS, a European Aerospace private company, case reported by Mager (2000), and NASA Langley Research Center (LaRC) case reported by Gough (2005). None of them report all the elements precisely and they are put together to show complementary aspects to tell the complete story. Some other cases are partially introduced for supporting the discussion points.

## *5.1. The Situation at the Starting Point*

There are several important points for starting the ICE implementation activity successfully. Clear problem statement, motivation of the team, and support from the managers are focused on in this case study.

### Clear Problems Statement and Motivation of the Team

All three organizations identified their problems and the motivation to implement the ICE clearly at the start-up. They are all very similar as the early adopters identified and reported. One is the need to improve on inefficient design process. The problem in the company B was the long time duration between the meetings. The chance of team communications were stated, "Whereas subsystem engineers would often have to wait at least a day and often up to a week for a design review meeting....".

Gough (2005) also reported LaRC had similar problem for which their project used the "work-and-meet" method. The engineers in a project team met and discussed with the results which they accomplished a few days ago and informed each other of new issues, then, they went back to their place with new tasks. The low efficiency and productivity caused important information to be lost or viable alternative solutions sometimes ignored. SDO defined the clear goal by setting objectives to implement the ICE with some tangible metrics and targets as follows.

- The focus of the SDO was placed on satellite system design instead of overall space mission design.
- Establish concept studies and binding proposals four times faster with half the budget and better with respect to overall consistency, number of alternatives considered, traceability and reproducibility of the process.
- Solve the problem of "team building" by ensuring the availability of experienced people as a well trained process oriented team instead of putting together a group of individuals,
- Solve the problem of obtaining overall consistency and controllability of the generation of "the solution" without traceability ending up in a "surprise" and the end of the process with very limited capability to redirect.

They also stated, "Beyond all this we wanted to create an environment to develop new ways in collaboration and in the application of state of the art IT technologies.

It is very important for the design teams to understand and feel the importance and the value of making changes since it is the team itself who exerts a big effort to implement and use ICE. Clear goals also motivate the team by letting them understand where they are and how they made progress toward the goals.

### Support from the Management

The heavy support from the management, especially high-level management is also a very important point for the success of the activity. Stagney (Sept. 2003) reported that the sponsoring manager in the Company B gave the complete support for the team. All the work to achieve the vision he had laid out was authorized and funded in his department. Once the budget allocated for ICE implementation was depleted, another account was charged for it. This sent a clear signal to all involved that the project had absolute support and efficiently worked to overcome the initial resistance.

In the SDO case, Mager (2000) reported that the team was required to demonstrate the feasibility and success very quickly with a very low initial budget because SDO was from the pure industrial initiative. However, the large integrated satellite design tool was already under development when they started the ICE implementation .The integrated satellite design tool which was named as MuSSat was developed under close co-operation with Technical University of Munich. Mager (2000) documented "This aimed to establish a tool which supports a higher degree of understanding and maintainability for a system of interconnected spreadsheets." This was actually showing the strong support the ICE concept implementation from the management by investing in the satellite design tools.

Thus, substantial support and resource allocation is made in these cases. These are not the exception because JPL/NASA, ESTEC/ESA, et al invested a lot to implement the ICE. More importantly, the team was highly motivated to work on the project when the manager who should make decision and have responsibility showed the attitude and took action for the complete support. It also works to convince the manager who is sending engineers to the design team to contribute to the design activity. This positive chain reaction leads to good team work and high performance.

## *5.2. Implementation*

### Team building

As Stagney (Sept. 2003) mentioned, "A dedicated standing design team is the most powerful approach" is a general lessons learnt. All the design teams in Company B, SDO and LaRC were formed as standing teams. Company B started their activity with an interesting task to motivate their team to tackle these problems together. Stagney (Sept. 2003) reported that the design team worked together to identify the entire set of information that would be exchanged during the design session for the standard product. The result was "a massive table with several thousand pieces of information all exchanged manually". They realized how much complicated and large amounts of information exchange they carried out every time. They were highly motivated to try ICE implementation trial to make their work easier. Mager (2000) expressed the design team as "a virtual organization" and Astrium formulated the following basic teaming principles for SDO. The main principles are extracted as follows.

- Recruitment according to skills only – no constraints from the existing organizational units
- Maximum size of 15 members per study team
- Availability of 2 persons per role during the build-up phase
- No hierarchy – self organizing mini teams for each of the 15 roles maintain communication with the relevant engineering departments

The team worked together at least once a week for information exchange, decision making and for continuous refinement and developing the common understanding of the SDO process.

Even though some core engineers, usually the system engineers, led the ICE implementation activities, discipline engineers were not passive in the activity but actually they worked actively per their responsibilities. Sharing the goals in the entire team and letting the team member feel united was a big first step to success because the ICE just worked as how the team worked well together. The team members were almost fixed in the certain period and at least 2 engineers from a discipline, a young engineer and a senior engineer. It was supported not only in the SDO case, but also in LaRC case, JPL case reported by Knut (2000) and

ESTEC/ESA case by Bandecchi. This compensated for the capabilities of junior and senior engineers as mentioned in the company B case; The manager of a discipline engineering group suggested the team should be comprised of younger engineers who were more comfortable working with the complex design tools, ICEMaker in this case. But others argued that team should consist of more experienced senior experts for the design with robustness, manufacturability and consistency with the corporate legacies.

### Design Process Development

Since the ICE approach is a design method, the output of the design activities will not be much different between the classical approach and ICE approach. The main difference will be in the team communication process and operation of the design sessions. It becomes more important to control the electrical data and the design parameters for the system model through the network. Engineers use design tools in both approaches but the tools have to be integrated to some extent for quick turn around of analysis and design in the ICE approach. To build these models and environment, it requires identifying and defining the input and output interfaces for integrating the tools as a first step; in other words, the team has to know explicitly what they have been doing in the design activities.

As mentioned above, the team started to map all the information exchanged during the design activity based on the information provided from the discipline engineering group in the case of company B. Then, the subsystem designers developed their design tools to translate the inputs into the requested outputs. The tools were developed and integrated gradually by beginning with very simple designs for the "first-draft" of the tools to run very quickly. Stagney stated this was because team members could understand what worked and what didn't quickly to avoid working for months to develop complex models. Furthermore, the engineers reduced their anxiety for working in a new process drastically by practicing on designs which they were familiar with.

Similar development activity is documented more precisely in the Astrium case by Mager (2000). After the team understood the macro process and the micro processes to be followed in the design sessions, they focused on how to generate the required outputs from the available inputs based on the set of standard solutions, selection guidelines, and component databases supported by the real-time availability of the necessary tools with the bottom up approach. As a result, they found that the different disciplines had different level of design details and different roles. They had to achieve an agreed set of data and common understandings. A small core team generated an overall philosophy and talked to the representatives of all disciplines to do it. Then, they discussed and decided in the presence of the whole team which disciplines had to provide the required inputs leading to a consistent set of input output relationships. One thing worthwhile to mention is that they found it was obviously difficult to express everything in formal relationship. Mager (2000) classified information interfaces among the disciplines as follows;

- *Direct*: Mainstream information flow between disciplines, which is always needed and which can be clearly expressed (formally supported by tools)
- *Checklist*: issues, questions and constraints to be clarified with other disciplines, which are not always needed and which needs explanation or discussion (will be formally supported by tools)
- *Discussion*: Everything else (incl. everything forgotten above) to be clarified and discussed during the SDO team session

This means that the SDO team developed the system model quickly with the available information and applied the incremental improvement instead of developing the complex full model. When applying the process and model on the first application, the team was not sure how the ICE process worked while it ended up with the surprising success. They concluded the main reason of their success was due to the good team. The ICE approach gave them a high flexibility but the key factor was the capability of the team to control the process.

### Tools and Infrastructure Development

In the case of company B and Astrium, Stagney (Sept. 2003) and Mager (2000) mentioned that they developed the tools needed on their own after identifying the inputs and outputs required in the design sessions and allocating them to the engineering disciplines. It is the same in almost all the cases. It is not clearly documented what tools and how they were developed, but discipline engineers made that decision and naturally most of the tools were the corporate standard tools. One important point is to understand what will work and what won't in the real-time design sessions as the team in the company B had recognized at the early stage of the tool development. Stagney (Sept. 2003) mentioned that this knowledge helped the discipline engineers to develop their tools effectively. Beside the individual analysis tools, data management tool was another key essential tool in the ICE environment. The company B selected the ICEMaker which was developed to tie the design models or CAD tools together for real-time design in the California Institute of Technology. This MS Excel ™ based tool was adopted by JPL/NASA first and some organizations including LaRC followed. Astrium was developing their own tool called MuSSat but they used MS Excel ™ for data exchange until it became available. While both of the company spent several months to develop the full environment, no severe issues are reported. This is maybe because of the simplicity of MS Excel ™ and the familiarity to the engineers. Database and supporting software like automated documentation system are also the essential tools. Most of the organizations developed them but not mentioned was that they spent significant effort to build them.

### *5.3. Operation*

Basically, the company B, Astrium and LaRC implemented the ICE and achieved successes. Company B was capable of producing a new proposal in approximately 2/3 of the cycle time compared to the classical approach. Engineers liked to work with the ICE process and did not eager to go back to the old process. According to the report by Stagney (Sept. 2003), there were some problems, too.

First, some marketing people were reluctant to attend the sessions because they thought it was a waste of their time. While they played the important role to connect the customers and engineers by answering to the questions from engineers in the sessions, they did not design anything in the session and contributing to this was not thought as contributing to the marketing group. Similarly, the people in the operation division were indirectly linked to the design team and limiting the number of the members in the session, this resulted in their input coming too late and had huge impacts on cost or lead time.

Second, the design tools worked well for the person who developed them, but the individual toolset was highly customized and served merely to enhance the effectiveness of each designer. They had to be re-developed for different engineers and systems in the different categories. Stagney (Sept. 2003) concluded about the tool, "Real-time concurrent engineering is a process – not a technical tool – that is only as powerful as the team running it. To be effective, the team must first learn a new way of working together, define their unique design variables, build and validate their client models, then practice, learn and adapt. Any team is capable of becoming a high-performing RTCE team, but it will not happen over night."

Third, there were some cost issues. As related to the total cost of each new design, the managers were unable to see the improvements made by the team in the efficiency of their conceptual design process. The savings created by a more efficient preliminary design process were offset by other work. Discipline engineers were eager to work their individual project than the design to appeal their contribution to their bosses due to the heavy lay off caused by the market shrink in 2002 to 2003. At the same time, the team budget was running out and the old team members were not eager to help the new team members because they were not paid for helping them due to the budget problem.

It is not mentioned if they are still using ICE process in the Stagney's report (Sept. 2003) but at least the next generation of the new collaboration environment called MATE-Con process was not budgeted and developed, yet.

In the Astrium case, there mentioned minimal severe problems when they used SDO continuously and its operations became more routine and expanded it capabilities. As "The great success" hindered work in the classical approach, SDO is used more because it is thought as to provide well-harmonized system design in the shorter time in high chance. In general, SDO was a success but Mager (2000) pointed out that they have had some problems left to be solved. One basic problem was that the SDO always got different requirements for the system design. They expected to be able to develop the common design process or system model but it never happened. They were forced to develop and work under the dedicated process for each design activity. The other problems were caused by the high demand on SDO. First, the more SDO was used, the more team members become busy. They, however, belong to the engineering discipline groups and the limited availability for SDO made it difficult for teams to schedule the sessions. Then, they increased the team members but it slowed the design progress notably. New colleagues involved in SDO had to learn how to work under the ICE process and how to use the design tools developed for SDO. Second, two different teams required to run the ICE process at the same time with the single SDO facility due to the high demand. It seems like they succeeded in managing the schedule conflict but the increasing coordination activities slowed their design progress.

## *5.4. Summary*

A few of the ICE implementation success cases were introduced in this chapter. The essences of the success reported in the cases are almost the same with those of the engineering project: clearly defined and achievable goals, strong leadership and high capability of the team members, well defined and shared design process and adequate support system. The cases also revealed that running the ICE team in a limited size is feasible but it does not assure expanding the existence into the entire organization and completely replacing the "classical" team. There will be some organization structural problems, cultural problems, and other problems. Some surprising results are also reported. While they succeeded to reduce the design period and to increase the design quality, the company B did not see the cost reduction. Astrium did not see the common design process and required building the dedicated design process in every design activity.

These facts tell us that we should not try to implement the ICE just for making the team design activities easier with less effort. The ICE is actually the method to strengthen the design capability with substantial investment to achieve better quality designs efficiently in the short term. Cost reduction might be achieved after accumulating the design tools, design cases which are applicable as the design templates, and the widely shared design process. So the challenges are how to make sustainable growth toward the complete pervasion in the organization in the long term even if it reduces the merit of the initial quick success.

# *Chapter 6: Case Study Analysis*

In this chapter, the main case from organization A is analyzed from an SE perspective and cultural perspective, and by comparing to the reference cases. The goals of this analysis are understanding what the problems were and the roots of their failure, what they should or should not do, and how the ICE would be modified to fit the organization A and the traditional Japanese culture.

## *6.1. Analysis Overview from the Systems Engineering Perspective*

The ICE approach was totally new to the organization A and they tried to change their concept design approach from their classical approach to the ICE approach similar to the other organizations in the reference cases. The first step was understanding what the ICE was and how it worked by hiring a consultant. This is a very important action and the right step to take. However, they mainly worked to find how the tools were used and information was exchanged in the real-time session, and how to find the subsystem models and design parameters that the discipline engineers had. The actual current design process and total system model was left aside. They also could not define the clear goals or strategy to implement the ICE. These were the main sources of difficulty in their implementation trial. The continuous changes of the team member added additional challenges to building the entire process and system model. This was mainly due to the lack of support from important stakeholders including executive managers and discipline engineering group managers.

Eventually, they started from the easy tasks and fit themselves to the organizational constraints. They tried to build the ICE environment and tried to expand and improve incrementally. However, this could not unite the team well or shift the design approach. They avoided tackling changes of their design approach which conflicts with the ICE approach. A bottom-up approach did not work to change what people did not like to do. Above all, the organization A could not draw the whole picture of how they were going to use the ICE approach and how they move from the current classical approach to the ICE approach.

## *6.2. Analysis Overview from the Cultural Perspective*

The key cultural factors observed in the case of organization A were the flexible teamwork and human dependent design process. The team members often assigned their tasks not based on the disciplines but based on their capabilities. They also often worked together by stepping over their boundaries of the assignment. This flexibility and collaboration maximized the performance and output quality of the team. At the same time, this flexibility prevented them from defining the standard system models or standard tools because everyone used the different models and tools. They were not so flexible as the people, with long term employment allowing this. The design and analyses experiences were stored in the people. They could transfer their knowledge to the young engineers through collaboration and communication in the long term relationship. It has worked well in the Japanese culture for a long time. This human dependent work style is maintained by the hard work of the engineers and this might be the weak point of this style. The increasing speed of the technology innovation and product life cycle requires them to catch up the speed by more frequent and intensive communication and collaboration, but this approach will reach its limitation sometime. Therefore, incorporating the systems engineering capability will be essential but they have to consider their cultural background when trying to implement the ICE approach.

The proposals of ICE modification are: leverage the individual design capability with building the design tools, subsystem models and design process to leverage the individual design capability but leave the data exchange interface manual. Another one is simplifying the design tools for discipline engineers as much as possible.

## *6.3. Detailed Analysis*

There are several factors which led to the ICE implementation as unsuccessful in the organization A. These factors are categorized into 6 issues in this section to analyze what key factors and situations drove them to the failure from systems engineering and cultural perspectives.

### *6.3.1. Goal and Strategy Definition Issues*

The organization A set three main objectives for ICE implementation activity; drastically reducing the concept design study period, improving the quality of design output and reinforcing the satellite concept design skill in the organization as described in chapter 4. By definition, objectives are something that one's efforts are intended to achieve. These are not always quantitative and often indicate only what their effort will be for. Thus, the objectives that organization A established are not problematic. The issue was in the goals, strategy of their ICE implementation activity and the strategy how to utilize the ICE in the organization. The practical goals or strategies were not well established. In other words, the plan was unclear in regard to the desirable condition to be established and how the ICE could leverage their system development capability in the organization. The plan was unclear how to transform themselves from the current situation to the desirable situation. Only the practical images of desirable situation they'd had were about the CDC environment to perform the concept design, which are most visible element of the ICE approach.

This is because they did not know in detail how the ICE would be implemented and operated in the organizations which were successful with ICE. There were many missing pieces of information about the ICE. The IT support group tried to find them to define the goals and strategies while they were having consultation, demonstrations and even developments. This "trial and error" or "scrap and build" approach sometimes works well if they focused on identifying what environment should be built for the ICE operation and what is important for implementing and operating the ICE approach. However, the first several trials were not enough to start implementing the ICE approach for the concept design study in the organization. The unclear goals and strategy confused the design team and lost their way to step along.

These problems could be identified in the consultation if they were focused on these points and identified the strategies on how to develop the real-time design process and shift from the current situation to there, how and what tools were to be built and how to build the team with desired capabilities. The consultant beautifully demonstrated how the concurrent design works and what tools would work well among the high-end tools within the resource and capability of the organization A. The consultant extracted the subsystem models, parameters and formulas to design the subsystems well through the interview with the discipline engineers. Then, the contract was closed and not extended. The consultation did not show the implementation process. The pieces of the ICE were shown well but the development plans or key factors for the team development, design process and the infrastructures were left unknown.

### *6.3.2. Stakeholders' Engagement and Support Issues*

The leading team of this activity in the IT group was very small. It was doubled from 3 to 6 as the activity went on, but still too small to complete all the tasks to implement the ICE by themselves. It obviously needed the contribution of the discipline engineering groups and other stakeholders. This is the case for all the other organizations who successfully implemented the ICE. However, the engineers in other groups joined this activity with low motivation and little responsibilities in the organization A. This is because the discipline engineers were managed by their engineering group managers. Contributing to the ICE implementation activity was recognized as not a highly prioritized task for their engineers. The productivity and the value of the group were evaluated by the progress and outputs of their own research projects and the contribution to the ongoing spacecraft development projects as specialists but not by the contribution to other groups' program. It was natural behavior for those outside of the IT group to work passively.

While the successful ICE implementation might mitigate their workloads when they are assigned to the satellite concept design team, they were not highly motivated to dedicate to ICE implementation by increasing their workload even if it might be temporary. It was ambiguous if the ICE would bring enough benefits or how long it would take until the time to achieve benefit. The barrier of organization structure was higher than the leading team expected. The strategy and the implementation plan were not well developed to motivate the engineers for dedication.

If the IT support group could have any dedicated support from the engineering group managers and the executive managers, the situation might be much different. Unfortunately, it would be a tough request to the group because most of the activities in the organization A, especially the small size activity like this case, were usually executed by the bottom-up approach. When a group wanted to start an activity, it requested an approval and budget of the executive manager for the activity. Once it was approved, the group was allowed to work for it but they had to do all the negotiations with other groups to take their contributions. Once the activity had some success, the size of the activity would be increased and the higher management organized it for the department-wide activity. This heavy reliance on the bottom-up approach was partially ascribable to the Japanese culture. The famous examples are the QC circle and incremental improvement in production line workers which were often reported as a source of high quality in the Japanese automobile companies in 1980's. This approach often worked well in Japanese organization but the ICE implementation required some volume of the initial investment and the incremental improvement approach did not work well in this case. The support and leadership of the higher level management were the essential element of ICE implementation.

### *6.3.3. Team Building and Management Issues*

The pre-project manager concluded that it attributed the biggest key factor for successful mission feasibility analysis in organization A to the team with right capabilities of mission design, tool coding and real-time analysis operation. When they expanded the team outside of the core members in SD team in the IT support group, this factor disappeared and the ICE implementation did not go well. Mager (2000) reported the most important element of SDO is their team. Bandecchi (2000) explained that "Human resources are by far the most important and crucial element.". It is rather difficult to measure quantitatively how much the importance of the capabilities of the team compared to the design process, design tools or infrastructure. It is also difficult to measure how much capabilities in what fields for team members are required to form a "good" team. Thus, it can not be proved that the team building and management issue were the biggest factor of the ICE implementation failure but it was true that the team in the organization A missed the very important element for their activity. The ICE is just what supports the human activity. It works effectively and efficiently so that the team can work effectively and efficiently. The team can increase its performance but not its basic design capability with ICE at least in the short term operation. Further, only gathering good engineers does not always make a good team and this is the point the leaders have to work on for the team building and management. Then, the next questions are "what went wrong with the organization A?" and "Why the united and "good" team could not be built?".

There will be some reasons which explain these questions. First, the goals and the strategy how to implement and utilize ICE were unclear as mentioned above. This made the discipline engineers have the impression that working with the ICE process might give little merit to them. They just expected that extra tasks and efforts were required for the ICE implementation. It did require intensive efforts to change their working behavior to shift the totally new design process and environments. Nothing comes without paying the cost for it. But without recognizing the necessity to pay the cost, it rarely works.

Second, they thought the ICE approach would require higher workload than the classical approach they'd used. Because they were requested to build and use some design tools. They were requested to exchange the design parameters explicitly among the disciplines. Some engineers designed the system concept or examined the feasibility of the system with very simple calculations or sometimes judged only based on their experience. Additionally, the new policies of using high-end design tools and improving the quality of design by detailed analyses required additional efforts to what they were doing. Further, the ICE implementation activity was not incorporated as a part of the whole system development process improvement. At that time, the concept design was finished with rather rough analyses. The detailed analysis had performed in the following system design phase. While they performed more detailed design in the concept design phase and achieved some "front loading", they were not assured their effort would give some real value in the system design phase because the entire design process was not re-defined according to the change of the role for the concept design phase. This strongly reflected the downside of a bottom-up approach.

Third, they did not have fixed team members and about a half of the engineers were changed in every design study. This liquidity of the team made it difficult to develop the design process and the toolsets because different engineers had their own strong fields of specialty, own design models, own design tools, and own design process. According to the reference cases, all organizations formed the teams with fixed members. The fixed and dedicated team makes the

ICE implementation easier because it enhances sharing the vision, progress and the problems the entire team and members are facing through smooth and intensive communication. It helps to form the tightly united team. Also, it makes it easier to define the system models and interfaces among the disciplines. Of course there are some down sides for the fixed team. The company B found that the tools developed were highly personalized and not flexible for other engineers. However, the team has to succeed in implementing and running the ICE approach at the end of the start up whatever it is. The team has to go beyond the threshold to convince the people the ICE does work for their organization even if it is only a prototype or specialized to the specific team. Then, the incremental performance improvement or generalization can be started on a larger scale and larger investment.

Actually there were several hurdles to form the fixed team in the organization A mainly due to the organization structure and the management structure. The concept design team was authorized as a special team in the organization wide and the leader assigned had the responsibility to the output. And the ICE implementation activity out of the IT support group was performed by the concept design team basis. This was the factor which had the biggest impact on the liquidity of the team. The team members were selected from the discipline engineering group but the group manager had the right to select the engineers to assign for the team even the team leader could give his request to the group managers. The R&D department in organization A had the functional structure and engineers were managed only by the group manager. They had their own research running in parallel and they had to manage the human resources in the groups. The concept design study started anytime as needed. The irregular schedule forced the discipline engineering groups to assign different engineers available. It was easier than forming a fixed team to persuade the discipline engineering group managers for making their engineers join the ICE implementation activity but this did not work well for the team management.

Lastly, the team members thought it would take quite some time to implement the ICE approach; design parameter identification, numerical system model development, clear assignment of tasks and responsibilities, and tool development. As described in chapter 4, the lead engineer and system engineers heavily controlled the design process in the classical approach. It was more like the centralized design team than the distributed design team. The discipline engineers required to change their mindset and behavior suddenly from "following and communicating with the leader" to "think about the whole system design process and communicate with other disciplines". The IT support group expected the discipline engineers work spontaneously to implement the ICE but it never happened.

In summary, the ICE implementation was driven by a "trial and error" approach by the IT support group, but it just confused the other team members and did not motivate them to dedicate to this activity. The continuously changing members and the team re-formation in every design study hampered the team work improvement.

### *6.3.4. Design Process Identification Issues*

The ICE implementation often started from identifying the current process and the procedures they use. This was observed in the cases from Mager (2000), Stagney (Sept. 2003) and they did not report any problem to perform this action. However ,the team in the organization A had some difficulty in it. The design process and procedures were not defined, which varied among the team leader. These attributes can be recognized as a typical sample of the organization with insufficient systems engineering capabilities. However, it had been utilized in the classical approach in the organization A while it had been gradually losing the advantage according to the fast technology changes and tight budget for the system development.

The keys for utilization of this attribute will be in the long term working experiences of the employees. Under the long term employment culture, the design and development experiences can be stored in the employees. These experiences are transferred to the junior engineers through coaching and collaboration. They heavily depend "on the job training (OJT)" traditionally in Japanese organizations. Currently this education process is reducing its weight but it still gives some influence on education and training in many Japanese organizations. Thus, they could turn out the experienced project managers and system engineers without the corporate standard management process. Different leaders could have implemented a different design philosophy and approach. They could lead the design study with their own processes and approaches which were inherited and modified through time in the organization.

These attributes have their downside, too. The concept design was recognized as highly iterative and heuristic activity. It was difficult for the team to identify the common understandings about what should be done in what order and by whom even for the SE and lead engineer. It is true that the concept design and system architecture development sometimes requires artistic factor in studies which are not logically deduced but this is not for the whole through the concept design study. They could not explain or visualize what they did in the concept design study with the classical approach. The design progress and its trajectory was also not trackable because the management and communication were intensively held through direct communication but not documented well. Absence of the standard process increased the difficulty.

The downside of the flexibility and intensive direct communication critically conflicted with the nature of the ICE approach. The ICE approach enhances the team communication by collocation, but visualizing the current design process and information transaction among the members are the key information to start to implement ICE environment as long as the design status sharing and discussions are held based on the numerical analyses. The organization A was doing well in the first characteristic of the ICE stated above, and they focused on gaining the second one from the ICE approach. It is almost impossible to define the real-time design process without the original design process because the ICE is to shorten the design cycle time and enhance the team communication.

### *6.3.5. System Model Definition Issues*

The standard system model for the concept design was not defined at that time in the organization A. Actually different types of the satellite had different models and interfaces, but some other organizations used standard templates to tailor it for each satellite. One example is ESTEC/ESA as Bandecchi (2000) introduced. Even though Stagney (Sept. 2003) and Aguilar

(1998) did not mention the existence of the system model explicitly, but they mentioned that all the parameters were identified, which were used in the classical approach.

Then, why and how could the organization A perform the concept design without the standard system model in the classical approach? There are 2 reasons which answer this question. First, some parts of the system could have designed and analyzed their feasibility with the engineering experience and by simple calculations. Second, the team worked flexibly, and tended to design and analyze as team oriented. The interface among the engineering disciplines and system changed flexibly based on the personal capability. These made it difficult to see the standard interfaces. People also worked on a subsystem or a task together without minding the personal obligations. For instance, if an engineer came up to an idea to design an other subsystem with different model or approach of the responsible engineer, they compared the models to develop better model or approach. Sometimes they merged their models each other. However, it was not shared with the other engineers not involved in the activity. Each individual stored the data, model, tools created but not shared through the data management system. Then, the existence of the multiple models makes it difficult to identify the standard models and interfaces. Further, these models for the system were developed through the design activity and the lack of the standard design process made it difficult to show how to develop the system and subsystem models explicitly.

The system model could be developed through the consultation which was described in chapter 4.3.2. Discipline engineers identified their subsystems and the parameter interfaces with other subsystems through consultation. The problem was they could not explain what parameters or models should be used for the concept design while they know the details of their subsystems. They made some assumptions based on their experiences instead of clarifying the parameter settings with other engineers or performing numerical calculations. Without the standard design output and required details, the accurate models were not be able to developed.

### *6.3.6. Real-time Design Tool Development Issues*

Engineers brought their design and analyses tools which they were familiar with into the ICE environment. This is observed in most of the reference cases. However, the organization A had to try to develop the new tools to try the ICE approach as described in chapter 4. In addition to the fact that people were not eager to use the unfamiliar tools, what were the issues for them? It was true that not all the discipline engineers did not have the capability to develop the general-purpose design and analysis tools but this was not the main issue.

One of the main issues in the tool development was the uncertainty of the degree of generalization for in-house tools which would be used in the real-time session. The engineers wanted to limit the capability of the tools as much as possible because generalization requires some additional time and cost to them. Further, no one could expect what kind of the flexibility would be actually used or how much the tools should be flexible. Even though some of them could handle the high-end tools but they mainly used them for the detailed analyses or designs in their researches. They did not know how to develop the simplified system models well enough for quick modification because they did not have the basic models. Either way, it required intensive work to develop the prototype tools. It was also unknown if the ICE approach would replace the classical approach. These factors had discouraged the discipline engineers to work on it due to their low priority on the ICE implementation. The possible solution would be the intensive support and contribution by IT support group as they developed the small design environment for the mission feasibility analyses in chapter 4.5. However, they were insufficient to cover it all. The flexibility of task assignment among the team member also increased the difficulty. The people can be flexible but the tools are not. The tool interfaces are not flexibly re-defined or the function of tools could not be exchanged flexibly.

Another issue is that they put too much focus on the data interfaces and connecting the tools. The flexible responsibility and task assignment among the team gives some difficulty to build the toolset and interfaces. The key point is smooth and quick information sharing. Automatic data exchange and collection is not necessary, though it will reduce the data handling and communication load from the members. Unfortunately, the main budget for the ICE implementation was from IT group and it required the contribution of IT to the successful ICE implementation.

### *6.3.7. Implementation Process Issue*

The first action taken by the organization A was learning what the ICE is and how it works from the consultant who knew and was experienced with the ICE. This idea itself was good. It was very important to well understand about what they were focusing on. The problem was they could not learn everything they had to know to complete the implementation in their organization. They learned about the most visible part of the ICE approach; tools and the system models. Specifically, that means how to run the tools and how to identify the system models which were expected as they had done.

While most organizations which implemented the ICE process confessed that the team and the process were the most important elements for successful implementation, it was very difficult to learn how to build and manage them from the consultation especially when they had the different cultures. The design process and the team management are organization dependent. These are not what they can copy from the other organizations. One thing they could do was to learn the implementation process overview and the key factors in design process and team management. Unfortunately they did not see the hidden problems they had at that time.

In addition to the interfaces mentioned in the previous section, they actually put too much attention on the tools and the models to run. Absence of the explicit design process brought confusion to the un-united team and allowed the discipline engineers to stick to the classical approach. A gradual transition strategy let the discipline engineers stay where they were because they did not have the chance to feel the merit of the ICE approach. There were some large gaps to overcome to let the ICE process work. The show stopper was the voluntary involvement of the discipline engineers in the ICE implementation. There were several barriers to form the special team derived from the organization structure and management structure. They thought it was the most feasible solution but it never worked as expected.

## *6.4. Recommendations to Avoid Failures*

Considering the analyses in the last 3 sections, it can be said that quick implementation of the ICE is difficult. It will require a considerable amount of effort. The first recommendation is learning from how to make successful implementation from the organizations that succeeded. Obviously they had missed some key factors for successful implementation. It is not enough to know how the ICE will work after they succeeded in the implementation. Initial momentum to move the people and the organization is not easy. They should build the overall implementation strategy by learning the key factors of ICE and the key factors of its implementation process.

The second recommendation is defining their concept design process in the classical approach as a first step of ICE implementation. This is almost unavoidable to define the real-time design process. While the real-time design session will be operated differently from the current meeting and individual work at the home office, the information and outputs needed in the design process won't be much different. Developing new design process, new design methods and new tools at the same time are too much. This forces the design team to throw away everything they have experienced before. Instead, they should define and share the design process first, then try to implement the ICE approach by implementing the real-time design methods, changing the tools and equipping the new working environment to mitigate the impact of changes.

The third recommendation is recording and tracking how the discipline engineers design their subsystem and how they define the other parameters in the concept design. This effort can be done well in parallel to the concept design activity. This is almost the same reason as the previous recommendation. It is best if some models are found in each discipline even if completed with the simple spreadsheet only. If the discipline engineer does not have any model, starting from defining what information will be required to judge based on their experiences and what information can be provided. That will be the good start. Once the engineers get used to explicitly defining and building their models, they can be stored in the server and reused. The challenge is the system engineers in IT support group should work with the engineers to define and build the model, and follow-up continuously. This is not much of exiting task as it is very basic and routine.

The last recommendation is focusing on the tool interface as a final step. Of course if it was easy to define the interfaces clearly or easy to connect the tools, there will be no reason to wait. However, once they find it will take some time to solve the problems, they should work on it after the design process definition and system model development are done well. What data have to be created and how to create them should be considered first, then how to exchange the data should follows. The tools might be changed or modified according to the choice of the data format or export/import tools, but again, the interfaces are of less importance than the models and the individual tools. Even if the engineers are forced to operate additional steps to exchange data or exchange the data manually, the design cycle goes on and the ICE approach can be operated while the speed might slow down and the benefit will be smaller. Nothing can start in perfect condition and incremental improvement will solve the problem in the future.

What the organization can try to do to avoid the ICE implementation failure was discussed in this section. Please note that there will be some chance these recommendations will not work because of the constraints the organization A might have; time, cost, human resource, organization structure, management structure. All the factors can not allow them to choose the ideal strategy and implementation process.

## *6.5. How can the ICE be modified to fit Japanese culture?*

It is really important to understand the key characteristics and factors of the new design approach before trying to embrace it. They have to change their working behavior, team communication style, engineering tools, environment, etc. for the implementation. This issue was discussed in the previous section, however, changing everything squarely as required won't always maximize the capabilities of the team. There are some things which can not be changed easily or quickly in the organization; common morale, common value metrics, common terminology, common basic behaviors, common knowledge and common thought. In short, we can call it the culture. Hence, the discussion will be focused on what part of the ICE approach can be modified to fit the Japanese organization, especially organization A in this section for the better implementation of the ICE approach.

How to incorporate the merit of ICE approach without disrupting the basic culture is not an easy question in this case because the ICE approach is developed to fit very different culture. Increasing their basic systems engineering capability is essential. Some changes are inevitable to let the core concept of the ICE approach works in the organization. One possible proposal is focusing on the design process and system model but keeping the manual data exchange procedure. The key is providing high quality information quickly through the entire team. As the communication among the team is kept intensive, leveraging the capability and visibility of the individuals will improve the team performance. This might not reduce the flexibility of the individual task assignment while the design parameters required to the team should be identified and tracked through the activity. The other proposal is to develop simple tools even for some parts of the whole system. It will get engineers used to designing with models, discussing with others based on the results of the analyses and improving them as their experiences grow. In any case, there won't be any quick and easy solution. The ICE will reflect the systems engineering capability of the organization and will work as efficiently as the team.

It is inevitable to define and "visualize" the design process, the system models under the tight competition and shorter product life cycle to efficiently collaborate and improve the design capabilities in the organization under the current tight competition. There will be the limitation in the fully human dependent design process and system models. It takes much effort and long time for the improvement and some risks to lose them. At least organization A and other traditional Japanese organization should admit the needs to change. Before improving the speed of design activity, how the team or corporate works should be understood. Every important decision should be done not by the tools but by the people who has the responsibility. Then, it is essential to understand how the team and the organization make decisions based on what information. This does not conflict with the flexible task assignment to the individuals at all. They should know clearly what is required for the entire team to cover. While the ICE approach implemented in some organizations will conflict with Japanese traditional culture, the basic concept of the ICE approach will not conflict with the Japanese culture. I believe it can be successfully implemented in the different way as shortly proposed above. Identifying the practical approach and its details are left for the future work. In any case, the most important thing to know for the design capability improvement is that the ICE helps the smooth communication and information sharing for the better decision, but it requires the basic engineering capability or the decision making capability as its basis.

# *Chapter 7: Summary and Conclusion*

This chapter summaries the findings in this research and concludes with several key understandings utilization of the ICE approach.

## *7.1. Summary of Findings*

As introduced in chapter 1, the initial motivation of this research on the ICE approach is to figure out the root causes of the ICE implementation failure in organization A. The key questions are;

- Are there any cultural factors which won't fit the Japanese national culture, which can explain why the ICE approach is used only in the organizations in the United States and Europe?
- What mistakes did the organization A make in terms of systems engineering and management?
- Then, what could they do for successful implementation given their situation?
- How can the ICE be modified to fit their culture if at all?

Through the intensive literature review in chapter 2, some key factors for successful implementation and utilization of the ICE approach are identified. The ICE approach is not the one-fit-all design tool and each organization needs to have its own clear goals and objectives to implement the ICE approach. Just reducing the design period can not be a good enough goal to motivate the team to work on that. The ICE implementation requires substantial investment to build the full prototype, and the dedicated support of the management and the united and highly skilled team are the key factors for the ICE implementation. Also, clarifying the design process, the system models and the interfaces among the disciplines are mandatory for the real-time sessions which bring most of the time savings and intensive communication among the team.

On the contrary, there were some ambiguities and the flexibility in their design process which led to short design period and high quality of the products in the traditional Japanese organizations. The ambiguity in design is solved through the feedback from the later phases performed in parallel. The entire team works flexibly without setting the clear interfaces among the engineers to maximize the total team performance. These characteristics seems to conflict with the basic concept of the ICE approach.

The research methods for the case studies are identified in chapter 3, and the chapter 4 and 5 discussed the case studies in chronological order. In the main case of the organization A, many issues are identified but the main points are;

- the consultation to understand the key factor for the implementation of the ICE approach was insufficient,
- the ambiguity of their design process, system models and responsibilities of each engineer made it difficult to build the real-time design environment,
- bottom-up culture and the organization structure prevented forming the dedicated fixed team, and
- the gradual transition from the classical to the ICE approach could not let them reach the point where the design team felt the merit of the ICE.

While none of these characteristics are observed in all the cases successful in ICE implementation in chapter 5, some organization faced two problems after their initial achievement.

- The tools and the models developed were team dependent and had difficulty in being transferred to the other team or even when substituting a team member.
- The design cost is never reduced due to the new tasks to fill the time freed by ICE.
- The design process and models are always dedicated and never developed as common ones as expected to reduce the time and cost.

Thus, the challenges left for the ICE approach itself is how to make sustainable growth toward the complete pervasion in the organization in the long term.

Deep analysis of the main case is performed from both systems engineering and cultural perspective comparing with the reference cases in chapter 6. All the issues in the seven categories are critical for the ICE implementation:

- unclear goals and strategies
- lack of stakeholders engagement
- lack of support from the top management
- not unified team with continuously changing members
- lack of the standard design process, system models and design tools
- unclear requirement on the design tools for real-time design sessions
- too much focus on the design tools and their interfaces

Removing these problems can lead them to success in the ICE implementation next time. However, it is not always good to follow exactly as the successful organizations did. Each organization is in the different situation. They have different objectives, application areas, technical strengths, corporate strategies, business environments, corporate cultures and national cultures. Two possible proposal to organization A are;

- focus on defining their design process and system models to be used but leave the data interfaces and exchange procedures as they are, and
- use simplest tools as much as possible for the quick development and modification to fit the flexible task assignment among the engineers.

In any case, the ICE approach implemented in some organizations conflict with the traditional Japanese culture. It won't work well in organization A and can be implemented in the different way. The most important thing is that ICE helps communication and it will work well only if the design team has the basic design capability and understanding how they decide things based on what information. No matter how much the communication and the analysis are done quickly, it does not leverage the basic design capability of the team.

## *7.2. Reflection on ICE and Conclusion*

Recalling the definition of the ICE approach by Parkin, et al (2003), which is cited in chapter 2.1, the ICE approach is a collaboration process and the quantitative real-time calculations are subsidiary. Thus, the key question for the ICE approach is how the team can collaborate for the better decision and better design. Under the ICE concept, collocation and real-time design are the proposed solutions. Most misunderstandings happen here to the organizations attracted by the ICE approach because the collocation and real-time design does not directly provide the better decision and design. The more important and basic capability for better decision and design is understanding how they are making decisions based on what information, or what logic and criteria are used for judgment. In other words, how well can the organization explicitly "visualize" the process and models to share through the entire organization for better teamwork? Therefore, as long as the organization has the "visualization" capability and is utilizing it, they can develop their own ICE approach to fit the organization because the collocation and real-time design can be realized in many ways.

Actually the biggest mistake made by organization A is that they tried to copy the way of collocation and real-time design which some successful organizations in the United States and Europe developed. If they have the same or similar culture, the developed process and environment for the ICE approach can be similar and the small difference can be neglected or covered by small modification, however, it can not be copied when the difference is large. The culture did matter for how to implement the ICE approach but the mistake is made in the different area.

Parkin, et al (2003) mentioned that there are 5 critical elements for successful implementation of ICE (see chapter 2.1). However, at least three elements out of five are definitely the key features for the better decision making and design regardless of using the ICE approach; the well-defined set of standard information product for output, well-understood procedures for collaboration, and the standing multidisciplinary team skilled in the tools and methods. Focusing on these factors is not considered as attractive as applying new trendy IT tools and new methods, so is actually quite difficult and slow in progress. Again, however, the "visualized" design process and models are not for the ICE approach implementation but they are the jewels of their design capability and the basis of improvement. If the organization A tries to implement the ICE approach by keeping this in mind, the ICE will work as a powerful tool and leverage their design capability in different ways to achieve the success as in cases of the United States and Europe.

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