Organizational Knowledge Creation Aspect of ETS-VIII Spacecraft Development

Katsuo YONEZAWA
Japan Aerospace Exploration Agency (JAXA)
2-1-1 Sengen, Tsukuba, Ibaraki 305-8505, Japan

ABSTRACT

Organizational knowledge creation (OKC) is increasingly essential in technology development of large-scale systems on information, communication, computer, and cybernetics. It is because innovation always emerges where those disciplines meet interactively to form interdisciplinary area, embedding full of tacit knowledge. This fact motivates us to investigate how to maximize dynamics of knowledge creation in organizational members at daily tasks for innovation in science and technology. The case study of ETS-8 Spacecraft Development is given here to examine the aspect of OKC.

Keywords: Organizational Knowledge Creation, OKC, Tacit Knowledge, OKC Management, ETS-8, LDR, SC

1. INTRODUCTION

Knowledge creation has been studied by Prof. Nonaka and others [1, 2], that can visualize in a new perspective a mechanism of innovation processes as a field of cyclic, synergetic interactions for spiral accumulation of organizational knowledge where each member codes in metaphor and modeling one's output of tacit knowledge into explicit knowledge, and distributes skillfully the explicit knowledge so as for other members to be able to decode their input of the tacit knowledge. Organizational knowledge creation (OKC) could be interpreted as a process that detects knowledge creation done by individuals, amplifies such knowledge in the organization, and makes the knowledge entrench in its organizational knowledge system. In this connection, we present our case study of OKC creation in the control systems development for *Engineering Test Satellite-VIII* (ETS-8), geostationary mobile communication spacecraft [3].

ETS-8 Overview

The experiments of mobile communications and multicasting by S-band and satellite navigation by L/S-band are the main objectives of ETS-8, which has been developed by JAXA to be launched into geostationary orbit at 146 degree East. Artist's Concept of ETS-8 on orbit is shown in Figure 1.

For the mobile communication and multicasting [4], two *Large Deployable Reflectors* (LDR, 17 meter by 19 meter, transmitting and receiving, respectively) and a 400W-class active phased array feeder with 31 SSPAs are installed in ETS-8. Three beams are used simultaneously to cover Japan and her neighboring region. Two kinds of onboard processors are installed, dedicating to voice and high-speed packet communications, respectively. The ground terminal for voice communications is as small as conventional cellular phone, and that for packet is in a similar size of notebook type PC. Satellite navigation, installing two Cesium clocks, covers Asia -Pacific hemisphere. The GPS-overlay experiment will be conducted by ground stations, given signals from GPS. The positioning accuracy is evaluated by changing RF frequency, code pattern and chip rate. The laser ranging determines the precise orbital parameters.

A flight model of the ETS-8 has already been manufactured and assembled, and has been under integrated system testing since Summer 2003, with all the development to be complete in Spring 2006. Figure 3 shows ETS-8 Flight Model under integration as of Summer 2003. The ETS-8 is to be launched by the H-IIA204 rocket from the Tanegashima Space Center in 2006.

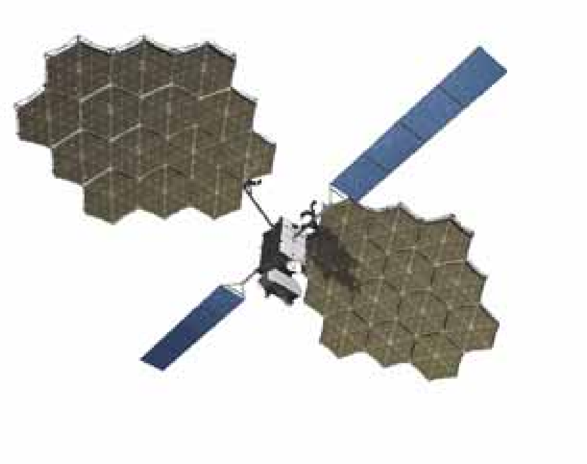

Figure 1. Artist's Concept of ETS-8 Spacecraft

2. ORGANIZATIONAL KNOWLEDGE CREATION (OKC)

For clarity of our view, knowledge is defined here as a stock of messages while information is as a flow of messages. *Tacit knowledge* is defined here as knowledge pertaining to personal, specific conditions so that it may be hard to express in language to others while *explicit knowledge* is able to communicate in language.

In the ancient Greek, sophists believed that one can only talk about what one does know, called explicit knowledge here. Thereby, if one is not able to express it articulately in language, one does not quite know what it is. In modern cognitive science, Polanyi [5] visualized that one is able to absorb tacit knowledge of others without language, recognizing the fact we know more than we can talk about. This means our explicit knowledge, expressible in words and numbers, is only a tip of the iceberg named knowledge. Wittgenstein [6] pointed out that there exists a domain of knowledge in our brain infeasible to be conveyed to others with a mere tool of language and thus impossible to be understood by others verbally since the knowledge does not exist in terms of language but as if it is personal perception of reality.

Heuristically, human brain looks like a digital computer of its own OS where tacit knowledge is coded in a programming language of its kind while explicit knowledge is expressed in a speaking language that plays a partial role of the input and output devices. Then, tacit knowledge coded in machine language is not available in terms of speaking language but expressible in images with other different I/O devices.

In this viewpoint, tacit knowledge is stored as a screen image in brain file so that it can be transferable in analogy, metaphor and model to some colleagues who happen to have the similar image in their brain file of tacit knowledge. Otherwise, they do fail in recognizing what the image is all about. One only sees what one is able to recognize through one's own mind image or picture.

Rigorously speaking, knowledge is created only by individuals. The role of organization is considered to help out creative persons by improving on their environment for knowledge creation. In this regard, OKC is a process to amplify organizationally such knowledge being created by individuals so that the knowledge can take root in the *organizational knowledge system*. This process takes place typically in a group of people interacting each other. Such group will eventually expands their activity from the inside of their organizational hierarchy, in horizontal boundaries and vertical levels, to the outside exceeding the boarder with other organizations.

Mechanism of OKC has been analyzed by his pioneering work of Nonaka [2] in terms of cyclic four-stage model to achieve spiral growth, as shown in Figure 2 of *OKC cycle*. *Knowledge transform* takes place bidirectionally from/to tacit knowledge to/from explicit knowledge. In the first stage, *collaboration* is a process of shaping a tacit knowledge in mental model, know-how, and skill out of experience in final design and production. In the second stage, *externalization* is a process of expressing the above tacit knowledge explicitly as a definite concept in language and diagram, utilizing metaphor, analogy and model. The third stage of *combination* is a process to combine the above concepts to form an integrated knowledge system, utilizing documents, meetings, and multimedia tools like internet. Multimedia accelerates the wide distribution of explicit knowledge. The fourth stage of *internalization* is a process to embody the above explicit knowledge into tacit knowledge, compiling the experience and expertise into documents and manuals.

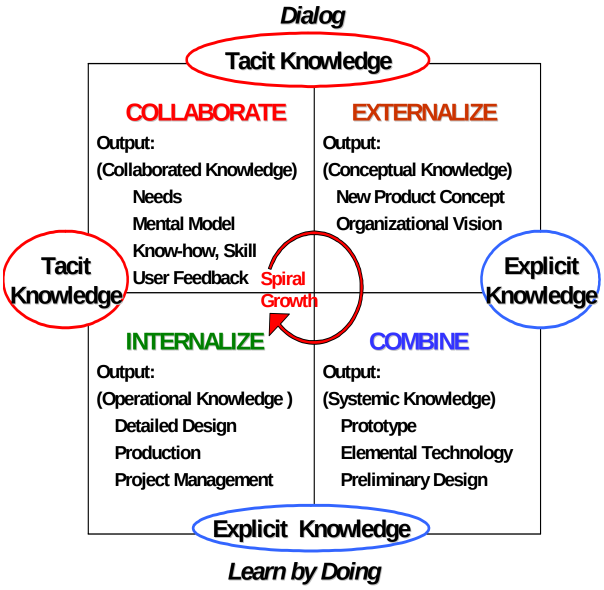

Figure 2. OKC Cycle (by Nonaka[2])

In this paper, we utilize the above *Nonaka model* as a basic tool of analyzing the OKC aspect of aerospace technology upon our case study of ETS-8 Spacecraft development.

3. KNOWLEDGE-CREATIVE ORGANIZATION

In this section, we illustrate key conditions necessary to make the organization *knowledge-creative*.

Knowledge Vision

It is an organizational objective that should mobilize the *knowledge spiral* (Figure 2). Thereby, it is very important for the management strategy to firstly create *knowledge vision* and then to think up such an organization to implement the vision. Presenting it to all of them, the management could behave as a catalyst or an enzyme to bring out from the members their own commitments.

Individual Autonomy

It is essential for the management to allow for individuals *self-reliance* to the extent possible. *Self-autonomy* is a power source of making individuals motivated so as to increase chances in new knowledge creation. Without *self-organization*, individuals may not realize their own commitments.

Creative Chaos

Chaos emerges when the organization confronts with crisis. Chaos excites the organization to interact with the outside environment and shakes up the conventional knowledge system. It can be *creative chaos* for organization members that give them a vital chance to renew the system leading to a new concept.

Information Redundancy

In a knowledge-creative organization, information is distributed and shared redundantly among the members at large whether or not it is essential for them now. Although it seems useless at one time, organizational *information redundancy* is found important for the smoother transfer of tacit knowledge among members. One member becomes easier to clarify critical issues, stepping in the expertise of other members.

Requisite Variety

Ashby [7] states that a competent organization should contain the same degree of variety in itself in order to respond to the complexity of a new environment. It is essential for the organization and its members to be upgraded in capability of problem-solving. To make it adaptive to ever-changing environments, the organization should keep itself renewing its knowledge system.

4. SPACECRAFT DESIGN ISSUES

In this section, we illustrate typical engineering issues, brief but heuristic, to highlight the area of combined technologies in spacecraft designs, where organizational knowledge creation is significant for *problem-solving*. Where applicable, the case-study of ETS-8 is mentioned.

Risk management

The project team in developing a new spacecraft for high mission success needs to pay laborious efforts in risk managements to identify, assess, mitigate, and track risks. The project team layout a risk management plan by carrying out risk analysis out of their own expertise, to decrease risk events potential in each phase of design, production, test, and operation, as well as to minimize losses in case of such risk events actually happened. Effectiveness of risk management to maximize mission success depends highly upon past experience and expertise of engineers involved from the plan of controlling risks through the implementation, where *organizational knowledge system* takes powerful roles.

Failure Mode Effects Analysis (FMEA) is a standard tool of risk analysis. There are many answers for extracting critical risk items and weighting those risks in spillover effects. FMEA can foresee and screen out major critical items for effective design follow-ups if *organizational expertise* imbedded in individual engineers may be fully integrated into the analysis. While key components kept as redundant as possible, ETS-8 tracked down single-point failures (such as apogee engine, powerline) that might paralyze the operations of system and mission functions upon their occurrence, and provided effective measures for abating the probability of such failures.

It is essential to share risk/failure information, past and current, among relevant organizations, to prevent such similar failures from repeating in their separate projects. Compiling a database must give effective means for *information redundancy*. In this sense, JAXA has established a database of failure information system linking via LAN the relevant organizations and contractors bidirectionally to make the information promptly available for mutual benefit.

Figure 3. ETS-8 Flight Model Integration (Summer 2003)

Hierarchy problem in redundant spacecraft computers

To enhance reliability, spacecraft is equipped with computers in redundancy. This design, however, creates an issue of how to choose a primal computer out of redundant computers. The redundancy management of on-board computers takes engineers to a paradoxical problem of letting one computer health-check other computers while the computer may be subject to troubles with equal probability. There are two approaches to tackle this issue for dual computers. Firstly, as in ETS-8, one computer is made operational while the other is stand-by for switch-over until the operational computer fails in built-in-tests. Secondly, two computers are made operational and compare processed data each other for compatibility. If discrepancy is identified, ground operators may choose which computer must be normal, or the third computer, when available, may replace them. This, however, must avoid the vicious cycle of majority vote that one computer system behaving oneself as normal is logically contradictive to diagnose the other computer systems if it is actually abnormal. Moreover, in reality, different timing signals among computers take complicated roles in making erroneous diagnosis.

ETS-8 Satellite Controller (SC) [3] employs world’s first 64-bit high-speed MPU developed for space applications. The design concept of SC has a high speed, large capacity OBC processing in integrated hardware and software three tasks of attitude control functions, telemetry and command processing functions, satellite management functions (heater, battery, FDIR, etc.). This provides a whole satellite with higher reliability, lower power consumption, more payload space, and lighter weight. The integrated OBC achieves an important role in alleviating time lags with its high-speed processing of algorithm so as to keep sufficient a frequency bandwidth for phase controls in ETS-8 Attitude Control System (ACS) that contains flexible structures in control loops.

As an ACS on-board function, the FDIR (Failure Detection, Isolation and Reorganization) diagnoses periodically data from sensors and actuators. Upon detecting a failure, the FDIR identifies to isolate the failed component, and switches to the redundant. The automatic processing classifies failures into three levels. In failures of Level 1 where SC is normal and operational, they are component failures detectable by SC software, go to automatic reconfiguration by isolating the failed and switching to the redundant. In failures of Level 2 where SC is abnormal, they go to switching the failed SC to the redundant, and require attitude re-acquisition upon recovery. In failures of Level 3, they are not disposed by switching to the redundant SC or by attitude re-acquisition, and have to wait for commands from the ground station.

High-voltage-breakdown problem in spacecraft power

Spacecraft power systems such as solar paddles, power lines, and power regulators, providing 100Vdc for example, should be carefully designed against high static voltage breakdown (HVBD) charged in space environment. In a strong period of solar activity, HVBD is critically caused by a tsunami of radioactive particles emanated from sun spots and solar flares. No perfect answers are available for designers against such HVBD. One remedy is to lower or switch off spacecraft powers upon solar activity alert information. Insulation materials used in power systems are inevitably exposed to orbit-periodic thermal cycles in cryogenic temperatures without sunlight and high temperatures with sunshine. If power harness, for example, happens to conceal defective spots in the insulation materials, in the long run it may be fatally damaged by HVBD with solar flare radiation and/or by thermal cycle damage.

Robustness problem of plastic materials in spacecraft

Fatal accidents in aerospace systems have always been happening in their hardware of combined technologies as well as combined operations. Behind the accidents, it is almost found true that each element of the hardware passed the preflight testing but the combined operation caused unexpected, catastrophic anomalies during the flight. For example, tragic Space Shuttle accidents in Challenger and Columbia were deeply related to the utilization of plastic materials. Namely, carbon fibers are made by the delicate manufacturing where mixing of ingredients and processes of heating and curing may not be fully controllable so that structural and thermal design margins of safety must be kept enough by the engineers upon using the carbon fibers to their systems. Ambiguities, however, remain. Sample testing of plastic materials, often, may not be a perfect answer since it is difficult to measure the actual distribution of homogeneity in ingredient-mixing, heating and curing in the overall volume of such materials.

Tripological problem of moving parts in spacecraft

In a tripological point of view, space environment is very risky for moving parts. It is well-known that metal to metal (typically Ti to Ti) surface contacts in moving parts tend to stick together in a vacuum condition, sometimes even forming metallic bond, as one body difficult to be separated. Surface contacts of diamond to diamond as well as diamond to metal are found strong. To avoid such surface contacts, solid lubricants such as molybdenum di-sulfide are coated on the surface but care must be given since it is easy to lose by mechanical shocks.

Pro-patent problem to interface in-house and outsourcing components

Starting from pro-patent policies of President Reagan in 1985, a trend of protecting intellectual proprietary rights has prevailed world-wide. Although it is significant, the pro-patent rule cast some adverse effects on a smooth flow of exchanging technical know-how in interfacing in-house and outsourcing components among engineers in both sides. Component suppliers tend not to provide design details even if such information is critical for component users to evaluate its compatibility with their system requirements, disturbing the users to employ the component in full capability. In turn, component users tend not to provide for component suppliers information on how they integrate the component into their systems with or without problems, leaving the supplier separated from users' direct feedbacks. In essence, communication among users and suppliers has become limited to the protected area of intellectual proprietary rights, sometimes called 'clean interface', seemingly disconnecting creative area of combined technologies existing among users and suppliers. In this regard, ETS-8 evaluated several key components by ground tests if they are compatible to ETS-8 flight environments.

5. OKC OUTLINE IN ETS-8 DEVELOPMENT

How was OKC integrated into the R&D project team?

ETS-8 Project with a budget of about $300M had been given only a dozen of engineers in JAXA, in accordance with the government-wide manpower ceiling, so that it needed efficient project management such as OKC to fill up the manpower shortage. Thus, *individual autonomy* became a guiding principle of the project team for OKC.

Members of the R&D project team had a certain level of explicit knowledge at the start. Tacit knowledge, invisible to the third party, took an essential role in R&D activities. Thereby, the R&D productivity depends upon how much of tacit knowledge in common the managers may share with the members. Thus, managers in a R&D project were chosen among those who share tacit knowledge in similarity to the possible extent with the members at large.

What issues resolved upon applying OKC to the R&D?

OKC makes it important to combine experts of different area into one team in R&D. This combination, however, took much time for the R&D team to become mobilized without any gaps of expertise in between. In the meantime, managers gave members opportunities of debates in weekly team meetings for shaping a sense of consensus. It was also the responsibility of managers for the members to be encouraged to expose to such meeting their crucial problems in hand frankly and timely for seeking a project-wide solution.

What was an output of OKC management?

Members of the project team do not solely depend upon explicit knowledge but attach importance to tacit knowledge so that comprehensive knowledge may be shaped up inside of the project team. Thereby, each of the members identified one's own viewpoint, extended one's comprehension to other area, and participated willingly in project-wide debates, leading the team to problem solving and enhancing the capability of the project team.

Managers of the project team do not only recognize the value of explicit knowledge but also that of tacit knowledge, devoting into the accumulation of tacit knowledge to increase the team power of OKC. Thereby, the managers grasped in their hands a new approach to strengthen R&D productivity. OKC Managers pay special attention not to allowing the members make easy technical compromise but to letting them make technical tradeoffs through hot debates.

What are issues leftover to future?

We obtained an empirical, golden rule for OKC that any task can be best handled by a team of few experts in different disciplines (typically, a pair of mechanical and electrical engineers). Our ETS-8 project office was organized as a flat structure of several task teams where the members serve one another as required. It is our future challenge of OKC management how we should organize a huge, but still highly-efficient, R&D project team with a kind of hierarchy structure made out of such small-member units.

6. OKC CASE STUDY IN ETS-8 DEVELOPMENT

In essence, ETS-8 spacecraft development as in Figure 3 is a composite of product innovations orchestrating process innovations in a wide spectrum.

Cross Organizational

ETS-8 satellite bus carries various payloads that comprise JAXA's LDR (the first of its kind to be deployed), a 400-W high-output phased array feeder (developed by ASC, CRL, NTT), a transponder (ASC), an on-board switchboard section for mobile communications (ASC, CRL), a highly precise time reference device (JAXA, CRL), and a feeder link device (JAXA).

In the framework of Nonaka Model (Figure 2), the process of LDR development may be described by the four stages.

At the stage of *Collaboration*, four cooperative organizations (CRL, NTT, ASC, and NASDA) recognized the importance and experimental needs of 21-th century mobile communications with a geostationary satellite with large-scale antennas, as a common area of cross-organizational expertise.

At the stage of *Externalization*, the concept of LDR was emerged as a connected system of automatic open/close umbrellas to meet the accommodation limit of weight and size to the satellite upon rocket launching. Namely, LDR must be folded in a cylindrical shape upon launch and expanded to a full extent on orbit. Cross organizational dialog identified more than a dozen of umbrella-like modules necessary for forming a 13m-effective aperture of parabola antenna.

At the stage of *Combination*, the feasibility of LDR was studied by design, fabrication, and test of prototype models, to screen out a best-fit mechanism out of the several candidates. Test data were cross-examined by experts in different disciplines from the cooperative organizations.

At the stage of *Internalization*, a pair of LDR flight models was designed in detail, produced, and tested for flight readiness. Throughout this stage, the design margins in deployment mechanism for robustness were implanted into the hardware.

In essence, this Nonaka model described the process of building up the *requisite variety* in the organization to meet such technical challenges.

LDR Development

LDR as in Figure 4 is a typical example of *knowledge vision* symbolizing a product of interdisciplinary technologies, combining organizational disciplines, and demonstrating dynamical interactions of knowledge creation from the deployment mechanism design to the on-orbit operation design. LDR, the concept of open-close-umbrella-like, light weight, modular deployable antenna was crystallized by the cross-organizational dialog of JAXA (then, NASDA) with NICT (then, CRL), NTT and ASC.

LDR is a world-first deployable flexible structure of the kind in space, and faces with new technical challenges where conventional expertise was not directly applicable. While the-state-of-the-art still depends on trial-and-error, the LDR development is a *creative chaos*, challenged to start with building up a workable knowledge on visualizing the on-orbit behavior of such large flexible structure under microgravity, among others. LDR is a 17m-by-19m structure consisting of 14 umbrella-like modules (8Kg each), folded into a cylindrical shape upon launch, deployed by expanding modules hinged together on orbit. With fully deployed in orbit, a pair of East and West LDRs spans as large as a pair of tennis courts. The reflector surface of each module is shaped by cables to form parabola and handcrafted to clothe with gold-coated Molybdenum mesh, a flexible but hard-to-ravel product made by Japanese traditional textile art of Kaga-Yuzen.

Figure 4. ETS-8 LDR Deployment Ground Test

LDR is unprecedented technology in *requisite variety* that is very hard to validate its deployment design only by ground tests because this huge thin space structure is strongly affected by gravity. Thus, to evaluate the design, a scale model was launched into space by Ariane 5 in Dec 2000. The scale model consists of half-scaled 7 modules, 6 meters in diameter, called LDREX, LDR Experiment. The fight test exposed both the limit of our explicit knowledge as well as the foresight of our tacit knowledge. Analyzing flight data and re-examining ground test results [4], the original design was evaluated and improved. The points of redesign are, 1) to constrain the flexible mesh of reflector in order to avoid entangling with truss membranes, 2) to add enforced-springs in order to increase the margin of safety in initial phase of deployment, and 3) to change the release sequence of hold-down mechanism in order to decrease the oscillation at release. Now, the flight models of LDR have been manufactured on these improved designs. Concurrently, the above design improvement is planned to re-evaluate by LDREX #2 onboard Ariane 5 in Spring 2006.

Flexible structure stabilization control

Information redundancy prevailing among relevant engineers was essential in baselining the control dynamics design of flexible structure for stabilization. Mode analysis to this date shows natural frequencies of flexible structures in ETS-8 are very low. In first-order vibration modes, LDR has an order of 0.1Hz, and Solar Paddle (PDL) has 0.08Hz. Hence, ETS-8 ACS [3] employs phase stabilization control for the range of low mode frequency and small damping, and applies gain stabilization control to the range of higher mode frequency with larger phase delay in sensors, actuators, and computation. Upon ground tests, it is too large to identify flexible structure parameters even briefly and too difficult to remove the influence of gravity from evaluating the parameters. Thus, through the*OKC cycle* of *knowledge trasform*, we set up the above satellite interface of limiting coupling coefficients as a design guideline of flexible structures, and carried out the structure designs of LDR and PDL. As to mode frequencies, the design target is within the tolerance of 20~30%.

7. LESSONS LEARNED

OKC Management is best described as a template of knowledge creation to explore a new frontier while learning by practice how to apply to each specific situation. We have reviewed our R& D activities in ETS-8 Spacecraft development in the framework of OKC management. We have identified unique features in terms of OKC concept; otherwise we seldom recognize what is really going on at the site of R & D activities. Among others, we list up here our findings and lessons learned, those to be considered as OKC templates for potential users of OKC management.

IT and OKC

It is no doubt that Information Technology (IT) takes an important role in vitalizing *OKC management*. The Internet makes explicit knowledge expand in multi-dimensional scale. To our caution, it provides us a flood of unclassified information whose creditability must be checked out by our responsibility. The structure of OKC is robust in cross-examining the creditability of such anonymous information.

Problem Solving

Technical issues cannot ever be solved by majority votes for consensus where tacit knowledge may seldom be involved. Technical issues are best discussed for decision making by several experts in various disciplines together. For instance, a team of four looks like a bridge game, say, an interactive playfield of *tacit knowledge*, where people are accustomed to recognizing 4-dimensional viewpoints each other, in a size of information and complexity known appropriate for the physiology of human brains.

Leadership Equations in R&D Management

R&D Productivity in a view of OKC has been assessed by a survey of managers to obtain empirical equations for productivity **P** in leadership **L**, manpower **M**, and facility **F**

$$\mathbf{P/L = L \cdot [M + F]} \quad \text{or} \quad \mathbf{P = L^{2} \cdot [M + F]} \qquad (1)$$

Then

$$\mathbf{\Delta P/P = 2\Delta L/L + (M/(M+F)) \cdot \Delta M/M + (F/(M+F)) \cdot \Delta F/F} \qquad (2)$$

where $\mathbf{\Delta P}$, $\mathbf{\Delta L}$, $\mathbf{\Delta M}$, $\mathbf{\Delta F}$ show small increments in **P**, **L**, **M**, **F**, respectively. Productivity is proportional to the square of leadership that should be kept greater than one, otherwise productivity decreases in the power of two. Evidently, a change in leadership **$\Delta L/L$** is two times as productive as changes in manpower **$\Delta M/M$** or facility **$\Delta F/F$**.

Leadership **L** may be expressed by an ad-hoc production function of tacit knowledge **T** and explicit knowledge **E** in management for a constant $0< C <1$ (say, $C=0.5$)

$$\mathbf{L = E^{C} \cdot T^{1-C}} \qquad (3)$$

Then

$$\Delta L/L = C\cdot \Delta E/E + (1-C)\cdot \Delta T/T \qquad (4)$$

A mere increase in information **$\Delta E/E$** may not fully explain an update in leadership **$\Delta L/L$** . Even without additional information **$\Delta E/E$**, an increment in tacit knowledge **$\Delta T/T$** alone may contribute to an increase in leadership **$\Delta L/L$** .

Technical Expertese Equations in R&D Activity

Problem solving capability **S** of technical experts in a view of OKC may be measured by an ad-hoc production equation in explicit and tacit knowledges, **E** and **T**, in expertise with a constant $0< C <1$ (say, $C=0.5$)

$$\mathbf{S = E^{C} \cdot T^{1-C}} \qquad (5)$$

Then

$$\Delta S/S = C\cdot \Delta E/E + (1-C)\cdot \Delta T/T \qquad (6)$$

indicating that an increase in problem-solving capability **$\Delta S/S$** comes from a linear combination of increases in explicit and tacit knowledges, **$\Delta E/E$** and **$\Delta T/T$**.

Fallacy of Aggregation

Aggregation of local optimizations does not always lead to Overall optimization. Overall optimization does not always imply the achievement of local optimizations. *OKC management* serves a mechanism of merging overall and local optimizations asymptotically into one viable solution from the both ends.

Fallacy of Reductionism

The division of a system into functions is based upon our belief of reductionism that a system can be divided into functions. This functional division embeds inescapably a blind spot of reductionism. Reductionism only counts up necessary conditions as explicit knowledge so that it may not always expose sufficient conditions which combine functions together into a system. At first, sufficient conditions may be visualized in *tacit knowledge*. The goal of design does not only check up necessary conditions but also verify sufficient conditions fulfilled.

Vicious Cycle of Faulty Designs or Manufacturing Defects

Manufacturing can be defined as a process to transcribe design information into a product. Manufacturing defects originate from unsuccessfully compiling into fabrication processes such vital design information that might be extracted from problem solving tasks in development phases. Know-how acquired by a development team is collection of *tacit knowledge* including color, sound, touch, smell, temperature, heat, vibration, and so forth in terms of five senses. It is a decisive factor how much of such know-how could be incorporated into procedures and training for manufacturing.

Principle of Design Sufficiency

Design can be sufficient for known parameters while it may not be sufficient for unknown parameters. Design margin is expected to absorb ambiguities. *Tacit knowledge* plays an essential role in allocating extra design margin against potential risks while explicit knowledge identifies design margin against known hazards.

Art of Balancing Organizational Style and Culture

Organizational Style is the standard of value, action, and judgment covering over a whole organization, as an adhesive governing individuals with invisible forces toward organizational objectives. Organizational Culture is a mechanism of exciting creative activities of individuals in an organization, accepting the individualism of value, judgment, and action. In fact, Organizational Style and Culture are not in conflict but in resonance to strengthen each other in the *OKC management*.

8. DISCUSSION

The case study of knowledge creation in the spacecraft development suggested the topics for further research:

Catalytic Management

Knowledge-creative organization is a kind of all-frequency oscillator-amplifier that should minimize various dumping factors against each member so as to maximize peak responses at resonance frequency of each member upon knowledge creation. Innovation arises in such a field where tacit and explicit knowledges interact back and forth while keeping *individual autonomy* active. OKC technology management may work as catalyst, enzyme, or resonator that may not create anything by itself but oscillate or amplify individual knowledge creation.

Dilemma in Design Standards for Sufficiency

Design Standards only list up necessary conditions as design guidelines and practices, but are not intended to provide sufficient conditions. One cannot beforehand list up design conditions for sufficiency that must be revealed afterwards only by testing the design results. Hence, even if their designs comply with the Standards, designers may face with bug and faults derived from such designs that do not fulfill sufficient but necessary conditions.

Nobodies can be escaped from responsibility of attaining full sufficiency in their designs. All of known facts on designs can be specified as necessary conditions. Design sufficiency is verifiable only after the mission operations complete. Nevertheless, unknown factors upon designs should be implicitly accounted for, with design margins to realize design sufficiency. It is a goal of *knowledge-creative design* that designers realize design sufficiency with the spiral interaction of their experience and expertise.

Blind Spots in Interface Designs

The larger the scale of a system grows, the more complex the interface of components and subsystems in a system becomes. In reality, the interface design is separated into components and subsystems at predetermined interface points while the interface integration is a task of polysynthesis to make a whole system operational. A system may pass all acceptance tests for its subsystems although they contain defects undetectable within the scope of such tests. Thereby, in case, blind spots in interface designs may be found at the last stage of full-scale system integration and test. *OKC cycle* may reduce such blind spots with spiral *knowledge transform*.

Allocation of Design Margins in Limited Resources

Nobody knows what kind of troubles will happen upon a new challenge. Design margin seeming inactive at normal conditions turns out frequently to be essential to maintaining the integrity of an overall system at marginal operations. Design resources, however, are limited so that designers cannot take into account all measures conceivable. Thereby, it is a heart of priority design where and how much the designers allocate margins within limited resources available to circumvent unanticipated troubles. Allocation of design margins may be a master minded task of

OKC managers and designers on where and how to imbed the margins absorbing design risks.

9. CONCLUSION

The concept of organizational knowledge creation (OKC) analyzed the mechanism of spiral technology development, highlighted the catalytic role of technology management in individual knowledge creation, and demonstrated the case study of ETS-8 spacecraft development here.

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