한국기계가공학회지, 제20권, 제5호, pp. 35～46(2021.05) ISSN 1598-6721(Print)
Journal of the Korean Society of Manufacturing Process Engineers, Vol. 20, No. 5, pp. 35~46(2021.05) ISSN 2288-0771(Online)

https://doi.org/10.14775/ksmpe.2021.20.05.035

A Study on the Improvement of Quality Management System to Improve Weapon System Performance

Ju-Sung Bong*, Il-Ho Baek*, Jang-Wook Hur*,#

*Department of Mechanical Engineering, Kumoh National Institute of Technology

무기체계 성능보장을 위한 품질관리 제도개선 연구

봉주성*, 백일호*, 허장욱*,#

*금오공과대학교 기계공학과

(Received 03 February 2021; received in revised form 22 March 2021; accepted 24 March 2021)

ABSTRACT

The purpose of this study is to establish effective quality control activities to maintain proper operation rates and improve the performance of research and development weapon systems. Quality control improvement measures suitable for the actual conditions of our military were identified by comparing the operational methods and advantages/disadvantages of the domestic quality control systems Defense Quality Management System and Defense Quality mark with those of the systems employed in the US(QPL and QML). In order to ensure the reliability of the weapon system, it is imperative to operate a design-oriented self-quality management system through manufacturing-oriented government-led inspection and to expand and reorganize the certification system divided into manufacturing items and companies.

Key Words : Quality Management(품질관리), QPL(제품 품질인증), QML(제조업체 품질인증), DQMS(국방품질경영시스템), DQ Mark(DQ 마크)

1. Introduction

Quality problems of weapon systems have been raised as an issue due to recent accidents or system failures, such as the formation of cracks in fire control units or the screw loosening problem in the K-11 rifle, in weapon systems that have been in operation after research & development (R&D), mass-production, and deployment.[1] Additionally, technological advances have led to weapon systems that are increasingly becoming complex, which is accompanied by the appearance of quality problems, making it difficult to maintain the defense-readiness condition and increasing the lifecycle cost. Therefore, various policy-making approaches and improved quality management tasks are required to achieve a paradigm shift to the reliability-based quality policy.

Corresponding Author : hhjw88@kumoh.ac.kr
Tel : +82-54-478-7399

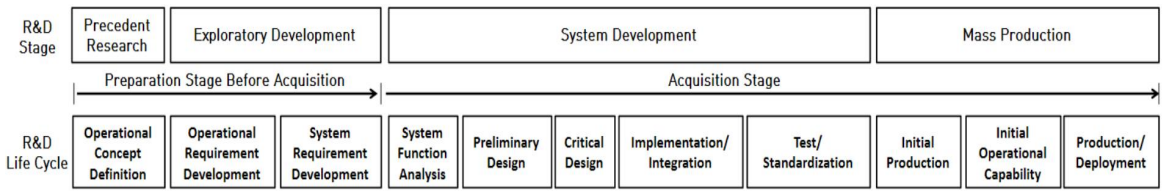

Fig. 1 Research & development stage

To increase the utilization rate and secure the reliability of a weapon system during its lifecycle, a limited competition should be considered so that only good companies with quality competence can participate in the project; this would prevent quality problems or possible nonperformance of a contract where companies lacking the competence win by bidding low. Thus, a system and policies for selecting the companies with a quality advantage based on excellent technological competence should be developed and implemented, so that the total force of the military equipment reserve can be maintained in battle-ready condition. The system should be prepared by considering practical limitations, so the selected companies can enhance quality management capabilities autonomously. In this article, we aim to propose measures to improve the quality management system suitable for the described situation by a comparison between the quality management system currently implemented for domestically developed weapon systems and those operated in the US.

2. Quality management system for weapon systems

2.1 Quality management activities for each lifecycle stage

Defense R&D projects, unlike civilian projects, have a consumer-oriented market structure, in which the demands are determined according to the total force integration initiative of the military. This means that the demands could be insignificant

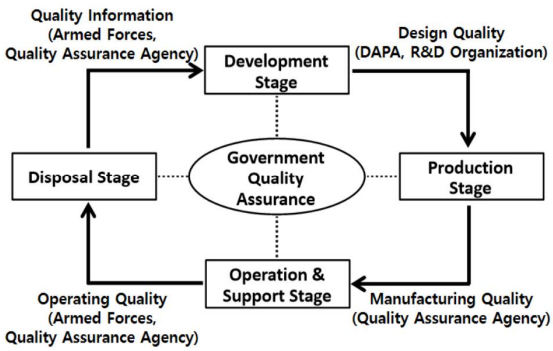

Fig. 2 Weapon system quality management activities

depending on the weapon system, although the defense R&D project may eventually reach a mass-production stage. The demands for defense R&D projects are decided between the demands for total force integration of the military and the limit of the defense budget, which makes it challenging to predict demands over more than five years decisively. Weapon system R&D is extensive and in various types. Weapon systems are operated in poor environments that cannot be compared to those for commercial products, and they are expected to operate over 20 to 30 years.

For such long-term operation, weapon systems require higher quality than commercial products, but the supply (demand) is limited, making it hard to expect a continuous improvement of quality. Once the demands are confirmed, weapon system R&D proceeds in separate stages of preliminary research, prototype development, system development, and mass- production, as illustrated in Fig. 1. The progress is checked at the meetings to review various designs before the transition to the next step.[4]

The R&D weapon system, unlike that introduced

Fig. 3 DQMS certification procedure

from overseas, is characterized by the government or a related agency gets involved from the developmental stage to assure quality. To meet the performance required by the military, the quality is designed in the developmental stage and implemented in the mass-production stage. Additionally, quality management activity is required to maintain and improve the quality on the operational stage. Such quality management activities for weapon systems, illustrated as in Fig. 2,[2] are made in all stages, including mass production, operations, maintenance, and disposal.[3] The main foundation for the quality management activities for the lifecycle stages of a weapon system is defense project management regulation, shown in Table 1.[4]

In the developmental stage, the Defense Acquisition Program Administration (DAPA) or the leading organization of the R&D project, the Agency for Defense Development (ADD) or a company, guarantees that it will meet the military requirements by examining performance, reliability, and mass-production. In the mass-production stage, the Defense Agency for Technology and Quality (DATQ) establishes and implements the quality management initiative for the contractor to perform self-monitoring and evaluation relating to the product warranty. Here, the DAPA specifies the types of quality assurance on the contract terms to satisfy the effective procurement and quality requirements, assigning the responsibility of quality to the company.[4,5]

Lastly, in the stage of operation, maintenance, and disposal, each military carries out the quality management activity during the operation of the

Table 1 Quality management activities by life cycle stage of weapon system

Division	Activity details	Execution department
Development stage	· Analyze military requirements and set quality characteristics · Configuration identification and reviewing defense standards(draft) · Production readiness review and manufacturing readiness assessment	DAPA, R&D organization
Production stage	· Production system inspection and quality verification of company · Technical guidance and confirmation of contract fulfillment · Quality improvement and production technology review · Vulnerable process and risk management · Assigning quality responsibility of the company(reflection of contract terms & conditions in the form of quality assurance, etc.)	DTaQ, DAPA
Operation support & disposal stage	· Quality maintenance activities during operation · Quality evaluation and improvement · Quality information feedback to development stage · Review of disposal of weapon system	Armed forces, DTaQ

Table 2 DQMS certified company incentives

Division	Certification incentives
Determination of the bidder for a competitive bidding contract	Grant company additional points(General item 1.0, food 0.7)
Defense product cost calculation profit compensation	Grants 10 points when evaluating management efforts
Evaluation of company selection proposal	Additional points(10%) for evaluation of technical capabilities
Select company of modification development support project	Additional points (1.0%) for company selection evaluation
Global defense industry strong companies nurture project	Additional points (0.5%) for company selection evaluation
Discovery of promising export items support project	Additional points (1.0%) for company selection evaluation
DQ mark certification audit	Exemption from factory inspection
Government quality management activities	Reduction of system evaluation targets
Change quality assurance type	Adjustment of quality assurance type to optional quality assurance type(II)

weapon system. For the items that frequently fail, quality evaluation or improvement can be performed through the DATQ, while a feedback system is maintained for seeking countermeasures at the time of development or performance improvement of the weapon system. A weapon system exceeding the economic repair limit should be considered for disposal.

2.2 Defense quality management system

The Defense Quality Management System (DQMS) induces the improvement of the capability of the defense company to plan the quality improvement of the weapon system and perform government quality management effectively at the same time. This system awards a certificate to eligible companies after judging their quality management system regarding approximately 70 requirements, including the ISO 9001 standards and defense-specific requirements. After reflected as the DATQ regulation, the DQMS certificate has been in operation after legislated as the defense business act in 2016.[4,6,7]

If a company—experienced with production and delivery of the weapon system procured by the DAPA to the center—requests the DQMS certificate to the DATQ, the work is done in the order shown in Fig. 3.[4,5]For certified companies, benefits are provided, such as merit awarded when judging the ability to fulfill the contract to determine the contractor from the winner at a competitive bid at the DAPA as shown in Table 2. [4,5,6,7]

The number of DQMS-certified companies is increasing each year, as shown in Fig. 4, with 188 in the year 2020[8]. Approximately 30% of 600 or so DAPA contractors have acquired the certificate annually. The maintained ratio of the certificate is 81% for large corporates, while 66% for small and medium-sized companies, which is relatively small.[3,6,8] This is deemed to be caused by frequent change of the person in charge of the work in the small and medium-sized companies, long-term absence of a contract, and management worsening in the defense market.[6]

Additionally, companies receive consulting service from a company specializing in quality management before the annual follow-up management reviews after the certification and the renewal inspection every three years. The time and expense taken for

Table 3 DQ mark certification status

Division	Year							Total
	2012	2013	2014	2015	2016	2017	2018	
Number of certified items	16	11	14	10	8	10	9	72
Number of companies	8	6	9	8	4	6	5	39

this is a burden for some small- and medium-sized companies, which tend to cancel the certification if judging the benefits from the certification to be small. For example, the screening reviews for the first-time DQMS certificate for a company hiring 45 employees cost approximately 1,400,000 KRW (unit price 20,000 KRW for seven days of review),[5] and the consulting expense related to the maintenance and renewal of the certificate is different for different companies depending on the scope and type of an evaluation target; still, it is presumed to exceed the expense of the review.

2.3 Defense quality certification mark

The Defense Quality (DQ) certification mark is an award certifying the competitiveness of technologies and quality as excellent products with export potential, so the DAPA can strengthen defense export competitiveness and support export expansion. This includes the defense materials and weapon systems that a domestic company produces with a plan to export. The target products possess the specifications applicable to the product tests, such as defense specifications, the requirements of the purchasing country, and company specifications.[7,9] Regarding defense material and weapon system, those products considered excellent quality or technologies are certified by having the DQ mark awarded by the government to improve export competitiveness and the capability of quality management. The steps of the DQ certification mark process are shown in Fig. 5.[9] In 2018, 72 items by 39 companies were certified, as shown in Table 3; the review cost per item is approximately 300,000 KRW.[8]

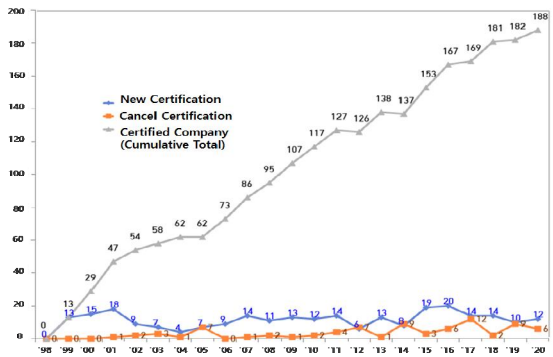

Fig. 4 DQMS certification trend

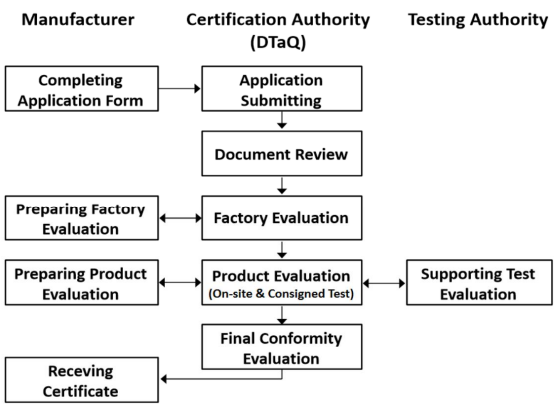

Fig. 5 DQ mark certification procedure

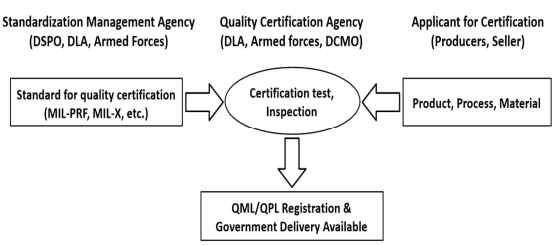

Fig. 6 QPL/QML operation concept

The DQ certification was reflected in the DATQ regulation in 2015. Companies that acquired the DQ certification mark are awarded benefits for recommendation priority for negotiation plan of an offsetting trade—i.e., the support priorities for training the workers specializing in export and for the expense of participating in domestic and international exhibitions.[9]

3. Quality management system of the US

3.1 Operation concept

In the US, government procurement utilizes the status information about the products, manufacturers, and bidding agencies that are eligible because they have been selected by previous tests and inspections. The qualification system is operated to verify through the test and inspection if the quality requirements are met and implemented independently from individual procurement in the stage before signing the contract. Types of certification are the Qualified Products List (QPL) for product quality certification, and the Qualified Manufacturers Lists (QML) for manufacturer quality certification.

The system certifies and manages the products and manufacturers that have passed the process of quality certification regarding the processing or the materials for the parts and components to be procured by the government.[7]

The quality certification process, which is done independently before the acquisition, is the step for proving via tests that the requirements of established specifications by the government are satisfied. The products or manufacturers that succeeded in passing the certification process are registered in the QPL or QML. Periodic inspection determines the maintenance of quality certification. Certification criteria for products are reflected on the federal standards, federal specifications, or military specifications, including the test and inspection criteria and process necessary for certification. The concept diagram of QPL/QML operation is as in Fig. 6.[10] If the manufacturer applies for certification, the quality certification institute determines whether the quality certification specification, such as military specification, is met. If it is met, the product or manufacturer will be registered in QPL/QML, after which the government receives the product through limited competition between the QPL- or QML-registered companies when announcing a request for bidding.

3.2 Product and manufacturer quality certifications (QPL/QML)

QPL is a list of products satisfying all the quality certification conditions after tests and inspection, and QML is a list of manufacturers satisfying all the quality conditions regarding the identical product that completed tests and inspection.[7,10]

QPL is a product certification that evaluates the conformity of product specifications. In contrast, QML confirms the total manufacturing capability (facility, manufacturing process, quality management system, etc.) for certifying a manufacturer and targets the items that are hard to certify for each product either because of the need for custom design, like electronic cards, or the availability of numerous types.

The QPL-certified items for major agencies are listed in Table 4; in March 2020, the total number of items was 754, including the 348 items by the US Navy, most of which are valves and bearings.[11]The QPL/QML certification process is shown in Fig. 7. ① The certifying agency announces the manufacturers to apply for certification when quality recertification is required due to issuance of new specifications or the revision of conventional specifications. ② If the manufacturer

Table 4 QPL certification status

Total	GSA	Army	Air Force	DLA	Navy
754	16	11	14	10	8

applies for product certification, the certifying agency provides the necessary information. ③ Certifying agency tests to check if the requirements defined in the QPL/QML test specification are satisfied; ④ audits the company's production facility (e.g., testing facility, processes, materials, manufacturing facility, testing capability, etc.); ⑤ notifies the company regarding the test results and the qualification for certification (registering the products or processes that passed the certification test in the QPL/QML lists); ⑥ has the certification status confirmed by certification managing agency every two years. Additionally, ⑦ retest and reinspection due to manufacturer modification of the product and alteration of the process, and ⑧ the cancellation of QPL/QML certification for reasons including the manufacturer not having met the specified requirements.[10]

3.3 Analysis of implications

QPL and QML are certification systems created in the US-based on the munition standardization policy. They, managed by the Defense Standardization Program Organization (DSPO), the US Department of Defense (DoD), aim to reduce the cost and time by skipping the certification item test for systematic management and procurement of an excellent product and its source. In South Korea, the quality management for the procurement of weapon systems is conducted after the contract, while in the US, a particular product is warranted for being suitable for the purpose of use on the stage before the contract. Consequently, an eligible company is selected as a contractor, thereby reducing the procurement period and establishing a reliable source of the product. That is, applying the QPL/QML operation criteria and process prevents the delay in delivery caused by test and inspection; this is resolved by evaluating the product and the company before the contract to shorten the execution process.

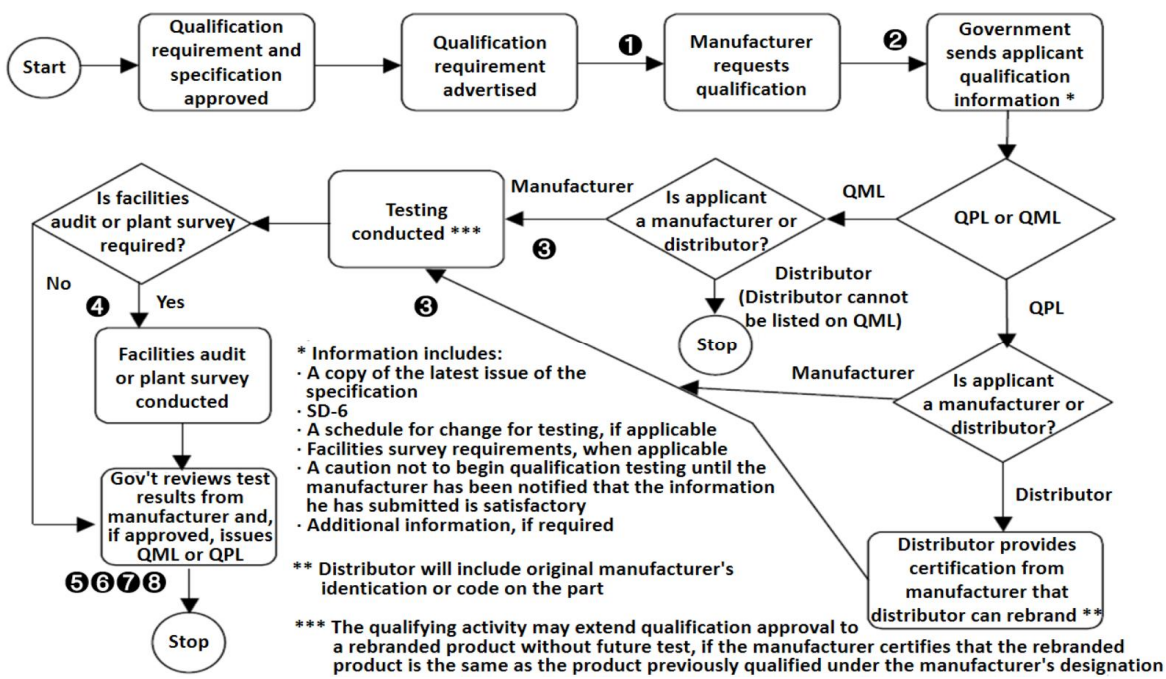

Fig. 7 QPL/QML certification procedure

Testing and evaluating the product and manufacturer before the contract shortens the execution process and also removes the need for repeated testing or inspections on the acquisition stage, saving the acquisition cost. Additionally, the evaluation of the product and manufacturer is objectified and standardized, and finally, a long-term relationship with the supplier is created to guarantee fulfillment of continuous requirements and quality improvement.

To promote the use of such a system, administrative support by the government and active participation by the companies are necessary. Besides, securing and expanding the market over a certain size is necessary for the company to generate profits from the acquisition of a certificate.

4. Measures to improve the quality management system

4.1 Reinforcing activities of design-oriented quality management

Quality management in the private sector has shifted from inspection-centered in the 1960s and process-centered in the 1980s to design-centered in the 2000s.[1] Additionally, most of the defects occurring during the mass-production phase can be resolved by minor alterations in technologies used or reworking, while the defects occurring during the developmental phase may cause failure with incomparably higher cost compared to those during the manufacturing phase.

Therefore, the measures should be sought after confirming the quality problems in the mass-production aspect during the developmental phase to acquire a high-quality weapon system for reducing the required expense within the total lifecycle and increasing the operation rate. To achieve this, possible types of failure should be identified accurately by the Failure Mode & Effect Analysis (FMEA) in the developmental stage to judge their impact and analyze the design alternative to plan quality improvement. In the stages of basic design and detailed design, the structure and function of the weapon system should be analyzed to predict potential types and severity of a failure; step-by-step design optimization should be implemented in response to the predictions. Active handling or work is required, such as utilizing the field operation data of a similar weapon system for the conventional quality management that is centered around the production stage to validate the FEMA result (Table 5).

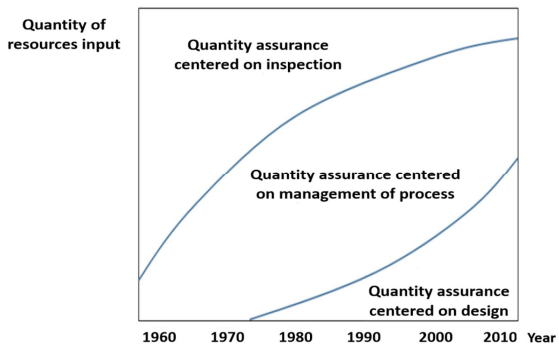

Fig. 8 Quality assurance development trend

According to the current defense project management regulations, when the DATQ conducts weapon system R&D, it should also support the DAPA or a leading R&D agency and prepare mass-production quality management,[2] which are lacking due to the limitations in clarifying roles and responsibilities and apportioning responsibility. Therefore, it should participate in basic design, detail design, test and evaluation, and specification process in order to clarify the quality management activities—reviewing various technological outputs, analyzing problems arising between mass-production and operation/maintenance, and suggesting an alternative solution—and the responsibilities of respective agencies for reinforcement of implementation.

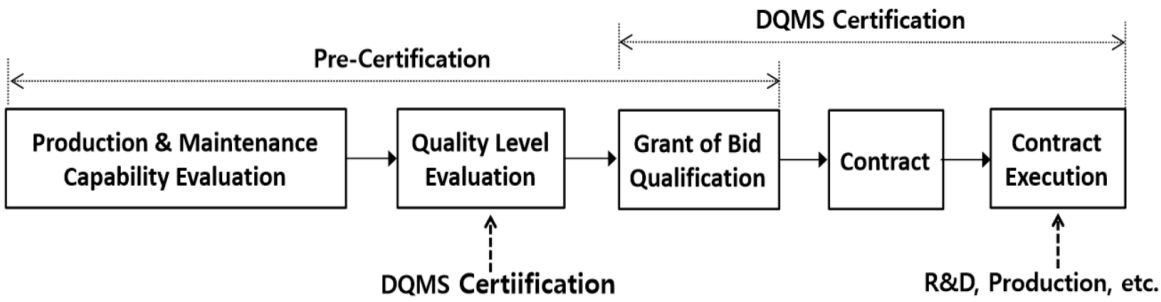

Fig. 9 Product certification procedure

4.2 Compensating the DQMS certification system

With advances and volume increases of the technologies applicable to weapon systems, expert knowledge is required for quality management. Further, the number of management targets is increasing, so companies with excellent quality management should consider running autonomous quality management in conjunction with DQMS certification.

Aligned with the defense R&D advancement and changing industry trends, the defense quality policies should transition into quality management using private companies to escape from the government-oriented quality management and expand the competitiveness of the companies by enabling market-oriented management. That is, in conjunction with the DQMS and manufacture certification, the companies with excellent competence should be given autonomous warranties while strengthening responsibilities.

Such a change allows strategies for quality improvement of defense companies and the establishment of an autonomous quality management system—the companies can manage the quality systematically using the measurement index created in advance. Additionally, it lets excellent companies enter the market while preventing ineligible companies from entering and, as a result, allows a strategic plan for quality improvement of weapon systems under development. Further, the quality management capability should be evaluated and managed to enable defense market entry to avoid the mass-production-oriented quality management after the contract and provide opportunities to those companies. Thus, the company should be certified for quality in conjunction with the DQMS certification system when entering the defense market, as shown in Fig. 9, and the award of merit should be expanded to the DQMS-certified companies at bidding to allow only high-quality companies to participate. Moreover, the utilization of the DQMS certification system is significantly lower in small- and medium-sized companies due to the cost burden and frequent change of persons on the job compared to in large corporations. Therefore, government-led supportive measures, customized to the small- and medium-sized companies, are needed, including reflecting the expense associated with DQMS certification in the contract price.

4.3 Implementing the product and manufacturer certification systems

Product certification systems should be introduced and operated to facilitate the supply of reliable products by excellent companies. Thus, similar to the QPL/QML system that is currently implemented in the US, the product certification for core parts and DQ marked items are shown in Fig. 10, and the manufacturer certification measures, such as

Table 5 Quality management system improvement plan

Division	Present	Improvement
Focus on quality management activities	Mass production stage	Design phase(FEMA+field data)
Leading quality management	Government	Company autonomous
DQMS certification costs	Company	Reflecting contract cost
Quality certification	Company certification(DQMS)	· Product certification · Manufacturing company certification

DQMS, should be considered, pilot-tested, and legislated to prepare evidence for expansion and push-forward.

The certification target for domestic production should be divided into product certification and manufacturer certification. The certification processes are illustrated in Fig. 11 and can be summarized as follows: ① Apply for certification after distinguishing a product from a manufacturer. ② Use the product and manufacturer information to select the item and manufacturer that are certification targets. For product certification, review focusing on core parts, DQ marked items, and KS items; for manufacturer certification, prioritize DQMS certification. ③ Perform document inspection for selected product or manufacturer. ④ Perform factory inspection of target product or manufacturer in terms of the number of related personnel, facility and equipment's suitability for certification criteria, and continuity in production.

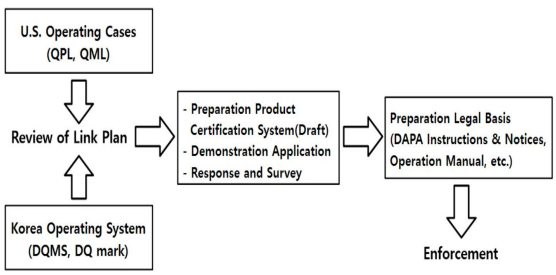

Fig. 10 Concept of certification system

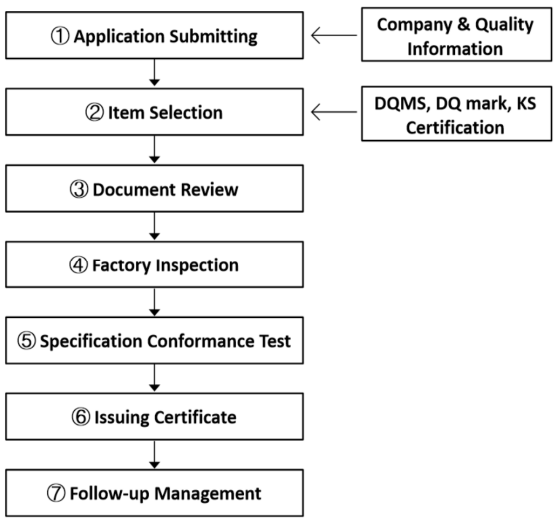

Fig. 11 Procedure of product and manufacturing company certification

⑤ Conduct the validation exam for satisfying specified requirements, and then, ⑥ if suitable, issue the certification separately for product and manufacturer. ⑦ After the certification, check certification maintenance by conducting follow-up management such as regular inspection, renewal inspection, and special inspection for altered specifications.

Regarding the products and manufacturers that have acquired certification, the companies should be provided with the benefits—e.g., autonomous quality assurance, optional contract status in various bids,

merit award—and the country's guarantee—i.e., DAPA—, domestically and globally. More companies should be led to participate through the legislation of the above, which can be used to improve the recognition of the manufacturers and increase domestic sales and exports. If product certification and manufacturer certification systems are implemented as described above, despite the recently increasing complexities in weapon systems relating to the trend of technological modernization, then all relevant certification systems will be prepared to allow the strategies for quality improvement of the product. By selecting and managing procurement sources who can deliver high-quality products continuously, low-price bidding of low-quality products could be prevented.

5. Conclusion

To maintain the defense-ready condition and to implement the economic operation of the R&D weapon system deployed on the field, improving the quality management system is necessary for guaranteeing the performance of weapon systems. We investigated the domestic quality management system, analyzed the system used in the US, and compared them to suggest the improvement plan suitable for our military's situation. The results are as follows:

1) The government-led inspection that is manufacturer-oriented should be expanded to the design-oriented quality management and company autonomous quality management system based on the use of the FMEA and field operational data.
2) The merit system related to selecting companies should be expanded to reinforce quality management through the DQMS certification system, and measures should be taken to support the small and medium-sized companies (e.g., by reflecting the expense associated with certification as cost).
3) The current manufacturer-oriented certification system, the DQMS, should be reorganized to distinguish product certification from manufacturer certification, QPL from QML, like in the US.

Acknowledgment

This study was the result of the "Supportive Project for the Grand ICT Research Center(IITP-2020-2020-0-01612)" by the Ministry of Science and ICT and the Institute of Information & Communications Technology Planning & Evaluation.

REFERENCES

1. Jung, Y. W., Yoo, H. J. and Song, K. S., "A Study on the Shift to the Reliability-Based Defense Quality Policy," Journal of Korean Society for Quality Management, Vol. 46, No. 2, pp. 193-210, 2018.
2. Kwon, K. J., Seo, H. D., Kim, M. J., Bang, J. M. and Lee, H. Y., "A Study on the System and Policy Direction of Military Quality Assurance," KID, pp. 34-37, 2017.
3. Yoo, H. J., Kim, Y. S., Kim, D. J., Jung, W., Park, J. W., Song, K. S., Ha, J. Y., Kim, J. E. and Ji, D. W., "A Study on the Introduction of Quality Certification of Military Products and Expansion of the Company's Autonomous", KSQM, pp. 201-240, 2018.
4. Defense Acquisition Program Management Regulation, DAPA, pp. 34-37, 2020.
5. Defense Acquisition Program Quality Management Regulation, DAPA, pp. 16-19, 2020.
6. Park, J. M., "Guideline for Implementing through Review of the Nonconformity Example of DQMS Certification Audit", DTaQ, pp. 1-8, 2020.
7. Shin, S. C., "A study on the Product Certification Scheme for Shipboard Equipment", Busan National University, pp. 160-168, 2017.

8. Reinforcement of Company Quality Capacity in Statistical Year Book of DTaQ 2019, DTaQ, pp. 76-79, 2019.
9. Notice on Operation of the DQ Mark Certification System, DAPA, pp. 2-8, 2020.
10. Lee, J. H., “A Report on Overseas Aircraft Part/Component Certification System”, DTaQ, pp. 3-20, 2010.
11. Program-Qualification in State of the Defense Standardization Program(An Overview of the DSP), DSPO, pp. 20-22, 2020.